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SUMMARY TECHNICAL REPORT

OF THE

NATIONAL DEFENSE RESEARCH COMMITTEE

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SUMMARY TECHNICAL REPORT OF DIVISION 4, NDRC

VOLUME 1

RADIO PROXIMITY FUZES FOR FIN-STABILIZED MISSILES

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
VANNEVAR BUSH, DIRECTOR

NATIONAL DEFENSE RESEARCH COMMITTEE
JAMES B. CONANT, CHAIRMAN

DIVISION 4
ALEXANDER ELLETT, CHIEF

WASHINGTON, D. C., 1946

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NOTES ON THE ORGANIZATION OF NDRC

The duties of the National Defense Research Committee were (1) to recommend to the Director of OSRD suitable projects and research programs on the instrumentalities of warfare, together with contract facilities for carrying out these projects and programs, and (2) to administer the technical and scientific work of the contracts. More specifically, NDRC functioned by initiating research projects on requests from the Army or the Navy, or on requests from an allied government transmitted through the Liaison Office of OSRD, or on its own considered initiative as a result of the experience of its members. Proposals prepared by the Division, Panel, or Committee for research contracts for performance of the work involved in such projects were first reviewed by NDRC, and if approved, recommended to the Director of OSRD. Upon approval of a proposal by the Director, a contract permitting maximum flexibility of scientific effort was arranged. The business aspects of the contract, including such matters as materials, clearances, vouchers, patents, priorities, legal matters, and administration of patent matters were handled by the Executive Secretary of OSRD.

Originally NDRC administered its work through five divisions, each headed by one of the NDRC members. These were:

Division A—Armor and Ordnance
Division B—Bombs, Fuels, Gases, & Chemical Problems
Division C—Communication and Transportation
Division D—Detection, Controls, and Instruments
Division E—Patents and Inventions

In a reorganization in the fall of 1942, twenty-three administrative divisions, panels, or committees were created, each with a chief selected on the basis of his outstanding work in the particular field. The NDRC members then became a reviewing and advisory group to the Director of OSRD. The final organization was as follows:

Division 1—Ballistic Research
Division 2—Effects of Impact and Explosion
Division 3—Rocket Ordnance
Division 4—Ordnance Accessories
Division 5—New Missiles
Division 6—Sub-Surface Warfare
Division 7—Fire Control
Division 8—Explosives
Division 9—Chemistry
Division 10—Absorbents and Aerosols
Division 11—Chemical Engineering
Division 12—Transportation
Division 13—Electrical Communication
Division 14—Radar
Division 15—Radio Coordination
Division 16—Optics and Camouflage
Division 17—Physics
Division 18—War Metallurgy
Division 19—Miscellaneous
Applied Mathematics Panel
Applied Psychology Panel
Committee on Propagation
Tropical Deterioration Administrative Committee

NDRC FOREWORD

As EVENTS of the years preceding 1940 revealed more and more clearly the seriousness of the world situation, many scientists in this country came to realize the need of organizing scientific research for service in a national emergency. Recommendations which they made to the White House were given careful and sympathetic attention, and as a result the National Defense Research Committee [NDRC] was formed by Executive Order of the President in the summer of 1940. The members of NDRC, appointed by the President, were instructed to supplement the work of the Army and the Navy in the development of the instrumentalities of war. A year later, upon the establishment of the Office of Scientific Research and Development [OSRD], NDRC became one of its units.

The Summary Technical Report of NDRC is a conscientious effort on the part of NDRC to summarize and evaluate its work and to present it in a useful and permanent form. It comprises some seventy volumes broken into groups corresponding to the NDRC Divisions, Panels, and Committees.

The Summary Technical Report of each Division, Panel, or Committee is an integral survey of the work of that group. The report of each group contains a summary of the report, stating the problems presented and the philosophy of attacking them, and summarizing the results of the research, development, and training activities undertaken. Some volumes may be "state of the art" treatises covering subjects to which various research groups have contributed information. Others may contain descriptions of devices developed in the laboratories. A master index of all these divisional, panel, and committee reports which together constitute the Summary Technical Report of NDRC is contained in a separate volume, which also includes the index of a microfilm record of pertinent technical laboratory reports and reference material.

Some of the NDRC-sponsored researches which had been declassified by the end of 1945 were of sufficient popular interest that it was found desirable to report them in the form of monographs, such as the series on radar by Division 14 and the monograph on sampling inspection by the Applied Mathematics Panel. Since the material treated in them is not duplicated in the Summary Technical Report of NDRC, the monographs are an important part of the story of these aspects of NDRC research.

In contrast to the information on radar, which is of widespread interest and much of which is released to the public, the research on subsurface warfare is largely classified and is of general interest to a more restricted group. As a consequence, the report of Division 6 is found almost entirely in its Summary Technical Report, which runs to over twenty volumes. The extent of the work of a Division cannot therefore be judged solely by the number of volumes devoted to it in the Summary Technical Report of NDRC; account must be taken of the monographs and available reports published elsewhere.

The program of Division 4 in the field of electronic ordnance provides an excellent example of the manner in which research and development work by a civilian technical group can complement and supplement work done by the Armed Services. The greatest responsibility of Division 4, under the leadership of Alexander Ellett, was to undertake the development of proximity fuzes for nonrotating or fin-stabilized missiles, such as bombs, rockets, and mortar shells.

Early work on fuzes of various types indicated that those operating through the use of electromagnetic waves offered the most promise; the eventual device depended on the doppler effect, combining the transmitted and received signals to create a low frequency beat which triggered an electronic switch. During the last phases of the war against Japan, approximately one-third of all the bomb fuzes used by carrier-based aircraft were proximity fuzes. For improving the accuracy of bombing operations, the Division developed the toss bombing technique, by which the effect of gravity on the flight path of the missile is estimated and allowed for. The success of this technique is demonstrated by its combat use, when a circle of probable error as low as 150 feet was obtained.

The Summary Technical Report of Division 4 was prepared under the direction of the Division Chief and has been authorized by him for publication. We wish to pay tribute to the enterprise and energy of the members of the Division, who worked so devotedly for its success.

VANNEVAR BUSH, Director
Office of Scientific Research and Development
J. B. CONANT, Chairman
National Defense Research Committee

FOREWORD

THE PRIMARY program of Division 4, NDRC, was development of proximity fuzes for bombs, rockets, and trench mortar projectiles. The National Bureau of Standards [NBS] provided facilities and personnel for the Division's Central Laboratory and the Division (or its predecessor, Section E of Division A) served as the principal liaison between NDRC and NBS. In large measure the developments presented in this Division 4 STR must be credited to the National Bureau of Standards. Credit also is due the Ordnance Department of the Army for excellent cooperation. The maintenance of effective liaison was due largely to Colonel H. S. Morton, whose enthusiasm for the program coupled with intelligent criticism and suggestions based on sound technical knowledge contributed much of value.

The present volume summarizes the Division's development of radio proximity fuzes. The technical direction of this development was throughout in the able hands of Harry Diamond, leader of the little radio fuze group organized at the Bureau of Standards in December 1940, and finally Chief of the Bureau's Ordnance Development Division. Throughout the program, he received invaluable technical assistance from W. S. Hinman, Jr., Chief Engineer of the aforementioned NBS division. The excellent presentation found here is due to the editor of these three volumes, A. V. Astin, Assistant Chief of the Ordnance Development Division, NBS.

Other Division 4 contractors made valuable contributions to particular projects on which they were engaged. Deserving of special mention are the University of Florida for work on trench mortar fuzes, the Globe-Union Company of Milwaukee for work on safety and arming devices and ceramic circuits, and the University of Iowa for improved recovery devices and a smooth working proof organization. The development of generator power supplies was largely carried out by the Westinghouse Company in Baltimore and by the Zenith Radio Corporation.

Reliability of radio fuzes depends at least as much on good production methods and techniques as upon good design. In the solution of production problems outstanding contributions were made by the Zell Corporation, Baltimore, and Bowen and Company, Bethesda, Maryland, who operated pilot lines; and by the Arnold Engineering Company, the Emerson Radio and Phonograph Corporation, the General Electric Company, the Globe-Union Company, the Philco Corporation, the Raytheon Manufacturing Company, the Sylvania Electric Products, Inc., the Westinghouse Electric and Manufacturing Company, the Rudolph Wurlitzer Company, and the Zenith Radio Corporation, who produced fuzes or fuze components.

ALEXANDER ELLETT
Chief, Division 4

PREFACE

THE Summary Technical Report of Division 4 has been prepared in three volumes: Volume 1, describing the work on radio proximity fuzes, the major work of the division; Volume 2, discussing bomb, rocket, and torpedo tossing, a new fire control method for airborne missiles; and Volume 3, a report on various miscellaneous projects. An overall summary of the Division 4 program appears as Chapter 1 in Volume 3.

The present volume treats the technical problems relating to the design, production, and use of radio proximity fuzes for fin-stabilized (nonrotating) missiles, including bombs, rockets, and trench mortar shells. For a treatment of work on fuzes for spin-stabilized projectiles, the reader is referred to the reports of Section T of OSRD. For work on other types of proximity fuzes for fin-stabilized missiles, the reader is referred to Volume 3 of the Division 4 STR. The latter reference includes a general survey of various types of proximity fuzes and a detailed summary of the work done by Division 4 on photoelectric fuzes.

A primary consideration in the preparation of this volume has been to arrange the material so that it will be useful for reference purposes. To fulfill this objective, the various chapters are reasonably self-contained, and each chapter may be read separately without too much loss in meaning. This mode of presentation has, of course, resulted in some duplication of material, but it is believed that the advantages justify the extra space required. Numerous cross references between the chapters are included to facilitate expansion or clarification of various items.

For the reader who is interested primarily in the essential operating characteristics of the radio proximity fuzes placed in production, Chapter 5, "Catalogue of Fuze Types," is the only part of this volume which need be read. The catalogue chapter also includes a description of the important features of design for each of the various fuzes.

The introduction to the volume (Chapter 1) explains the objectives of the development program, how radio fuzes operate, and includes a brief summary of the accomplishments in the development and production program.

Chapter 2 discusses in detail the basic theory of operation and shows how the required operating characteristics of a fuze may be converted into an engineering design problem. The material of Chapter 2 is fundamental to any fuze design involving interaction of radio waves with the target. Because of the great potential use of this theory in future development work, the treatment of Chapter 2 is much more thorough than would appear necessary merely as a summary of completed work.

The methods by which the electrical design problems were solved are discussed in Chapter 3. Section 3.4 of Chapter 3 deals with the design of generator power supplies, one of the outstanding features of the later fuzes developed by Division 4. Although this section is included in the electrical design chapter, it contains considerable material relating to the mechanical design of generators. A clear-cut separation of the mechanical and electrical design requirements for the generator was not practicable. Chapters 2 and 3 are quite technical in nature and will probably be of interest only to scientists and engineers. These chapters may be omitted by the nontechnical reader.

Chapter 4 analyzes the problems of mechanical design and layout and includes a treatment of the arming and safety features of the fuzes.

Chapter 6 describes the production methods and summarizes accomplishment in the production program. Since the problems of reducing a laboratory design of a proximity fuze to a model which could be built in mass production were fundamental to the entire program, the story of this chapter is of basic importance. It should be of interest to both the technical and the nontechnical reader.

Chapters 7 and 8 describe the methods of testing proximity fuzes in order that their quality might be evaluated and their performance under operational conditions predicted. The former chapter is concerned with laboratory test methods and quality control. A description of testing apparatus is included. The

latter chapter deals with field test methods and proving ground procedures in which operational conditions were simulated.

Chapter 9 gives a somewhat more detailed analysis of the operating characteristics of the fuzes than is given in Chapter 5 in that the results of all important tests which were carried out on the fuzes are summarized. The chapter includes evaluations of performance for each of the fuze types under a variety of operating conditions. The operational experience is also presented in this chapter.

An analysis of problems pertaining to countermeasures and counter-countermeasures has not been included in this volume.

The successful development of radio proximity fuzes, or VT fuzes as they are commonly called, involved the cooperative efforts of many organizations and individuals. A listing of all of the individuals who contributed to the success of the program would be an extremely difficult, perhaps even impossible, task. However, the organizations which participated in the development program are listed at the end of the volume.

This volume was prepared by the staff of the Ordnance Development Division of the National Bureau of Standards, which served as the central laboratories for Division 4. Reports of the various contractors to Division 4 have been used freely, and these are listed as references in the bibliography.

The editor wishes to take this opportunity to record thanks and appreciation for the efforts of the many individuals who cooperated in the preparation of the volume. In particular, some of these are: Dr. Robert D. Huntoon, who assisted in the overall planning of the volume and who was also the senior author of Chapter 2; Dr. Alexander Ellett and Mr. Harry Diamond, Chief, Division 4 and Chief, Ordnance Development Division, respectively, who offered valuable suggestions and advice on numerous items; other authors who are listed in the table of contents as well as in footnotes to the various sections which they prepared; Mr. Theodore C. Hellmers, who prepared the photographs used in this volume (unless credit is otherwise indicated); Mr. E. W. Hunt and his staff for their diligent and painstaking efforts in the preparation of other art work; Miss Lee Smolen and Mrs. Henrietta Leiner for preparation of bibliographical material; and Miss Helen Olmstead, Mrs. Betty Hallman, and Miss Jane Grant for their untiring efforts in the preparation, assembly, and correction of manuscripts.

A. V. ASTIN
Editor

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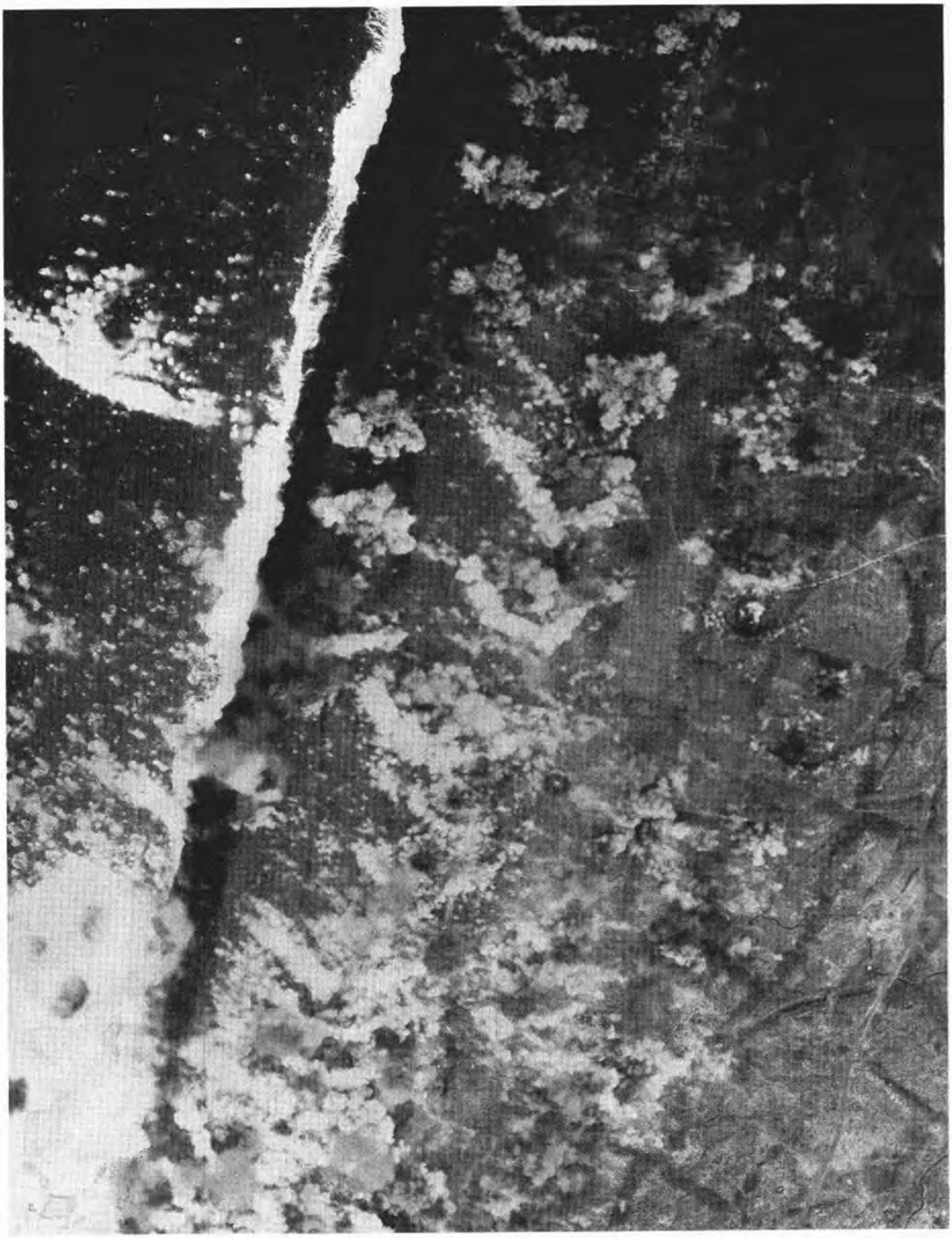

Strike photograph of the first operational use of proximity fuzed bombs. The target is the beach area of Iwo Jima during the pre-invasion bombing of the island. The characteristic crescent-shaped fragmentation patterns of air-burst bombs are clearly recognizable. (Army Air Force photograph.)

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Chapter 1

INTRODUCTION

1.1 OBJECTIVES AND MILITARY REQUIREMENTS

Radio proximity fuzes are intended to detonate missiles automatically upon approach to a target and at such a position along the flight path of the missile as to inflict maximum damage to the target.

The optimum position for detonation of the missile depends upon the nature of the target and the properties of the missile. Conditions of use divide possible targets into two major groups: (1) airborne targets, and (2) surface targets either on the ground or on water. These two applications are referred to variously as (1) antiaircraft, air-to-air, ground-to-air, and (2) ground-approach, air burst, air-to-ground, ground-to-ground.

As a class, proximity fuzes belong with time fuzes, in contrast with contact fuzes, since they are useful wherever contact of the missile with the target or penetration into the target is not necessary to inflict damage. Because of the automatically accurate nature of their operation, proximity fuzes not only extensively replace time fuzes, but they make possible many new and important applications for which time fuzes would be ineffective. They also replace contact fuzes in many applications where contact with an object, not necessarily the target, is used merely as a triggering operation for the fuzes and not because contact is essential to inflict damage.

Military requirements for proximity fuzes became specific and well defined only after the development had passed the exploratory stage. Initially the requirements were quite general; (1) the fuze should detonate the missile "in the vicinity" of the target, (2) the fuze should be as small and rugged as possible, (3) it should be safe for handling and operational use, (4) it should perform reliably under a wide range of service conditions, (5) it should require a minimum of special equipment and training for its operational use, (6) it should be relatively immune to possible enemy countermeasures, and (7) in antiaircraft weapons, it should have a self-destruction [SD] feature to operate, in case of a miss, after passing the target. Most of the foregoing requirements could not be more accurately specified until a certain amount of design experience was available or until actual fuzes were available for proving ground tests.

For example, the careful definition of the proper point on the trajectory for the fuze to function had to be based on experimental trials using fuzes against actual or simulated targets. Before the fuzes could be built for such tests, estimates were required concerning the expected optimum conditions. In the antiaircraft case, it was fairly obvious that the position of function should be matched to the dynamic fragmentation pattern of the missile so that the greatest number of fragments would be directed at the target. To achieve the proper directional sensitivity, a number of factors, as shown in Chapters 2 and 3, had to be balanced against each other, and the final specification of performance was based on numerous design compromises and field tests. In the ground target case, no experimentally verified optimum burst heights were available until the end of 1944 and then only for limited types of missiles and targets.[a] For many important ground target applications, optimum burst heights are still undetermined.

Some of the mechanical features were capable of more exact specification. Although small size and ruggedness were objectives toward which improvement was continuous, certain minimum requirements were definite very early in the program. Bomb fuzes were to be ballistically interchangeable with regular fuzes so that their use would require no modifications in bombing tables. Available stowage space in bomb bays made it necessary to impose limitations on overall length, and a maximum extension of 5 in. beyond the nose of the bomb was prescribed, although shorter fuzes were pre-

[a] These statements refer specifically to the fuzes for fin-stabilized or nonrotating missiles, such as bombs, rockets, and trench-mortar shells.

ferred. Standard fuze-well cavities in bombs fixed other dimensions. A minimum requirement on ruggedness was that the fuze withstand any vibrations or accelerations of the missile. There were also standard military rough-handling specifications but these were more of a requirement for packaging than for fuze design.

The arming and safety requirements, with one important exception, had to be worked out experimentally as the development progressed. The exception was the specification for an interrupted powder train between the detonator and booster, a standard Army Ordnance technique which was required of all proximity fuzes. Since proximity fuzes are, by their very nature, susceptible to their surroundings and unable to distinguish between friendly and enemy targets, the arming problem is appreciably different than with ordinary fuzes. In general, longer "safe" times after firing or release of the missile are desired for proximity fuzes, but an ideal safe period compromises the usefulness of the weapon. The details of the development of the arming and safety features and requirements are discussed in Chapter 4.

The very necessary exploratory work on radio proximity fuzes, was done under rather general requests from the Services, including a conference on August 12, 1940, between representatives of the Navy Bureau of Ordnance and NDRC;[1] Projects OD-27, dated January 14, 1941, and OD-33, dated June 11, 1941, of the Army Ordnance Department; and Project CWS-19, dated August 30, 1941, from the Chemical Warfare Service. The pertinent military characteristics for fuzes covered by these authorizations were essentially as outlined.

After laboratory development and field tests had established general possibilities and limits for radio proximity fuzes, specific Service requirements were put forth based on anticipated operational needs. The first major project which was carried through to large-scale production was for the T-5 fuze to be used with the Army's $4\frac{1}{2}$-in. (M-8) rocket. The desired characteristics for this fuze[2,3] were, in addition to the general requirements stated above, (1) the complete fuze should fit into a cylindrical container approximately $2\frac{3}{4}$ in. in diameter and 5 in. long, with an allowable conical extension on the front end of the cylinder about 2 in.; (2) at least 50 per cent of the fuzes were required to function in the vicinity of an airplane target when fired on the rocket and within the lethal range of the fragments of the rocket; (3) the fuze was to be armed and operative approximately $\frac{1}{2}$ sec after firing; and (4) the fuze should have an SD element operating approximately 9 sec after firing.

The T-5 fuze project was limited in that the intended use was confined to a single missile and for a single application, antiaircraft. It was complicated by the fact that the design of the missile itself was not complete and its dynamic fragmentation pattern was unknown. A dynamic fragmentation pattern was assumed from information supplied by the Services, but, as shown in Section 1.5, the assumptions were not strictly accurate. One very important compromise was made in the requirements for the T-5 fuze from the ultimate Service needs. This was in respect to the temperature range throughout which the fuze could be used. Unimpaired operation between -40 and $+160$ F was desired, but because of the limitations of the dry batteries which were to be used to power the fuzes the low-temperature requirement was waived. Actually, the relaxing of this requirement in the fuze did not impair the usefulness of the complete weapon since the rocket itself had low-temperature limitations not too dissimilar from those of the fuze. In order to reduce limitations due to possible deterioration of the battery power supply during shipment and storage, the design was made to allow final assembly of the fuze in the field using freshly tested batteries.

Experience gained in the development and production of the T-5 fuze, combined with simultaneous investigations for improved power supplies (Project SC-40), made possible much expanded, more rigorous, and more specific requirements for other radio proximity fuzes. These included fuzes for the following: (1) 10,000-lb light-case [LC] bomb, (2) 4,000-lb LC bomb, (3) 2,000-lb general purpose [GP] bombs against both land- and water-borne targets, (4) 2,000-lb glider and controllable bombs, (5) 1,000-lb GP bombs against water-borne

targets, (6) antiaircraft bombs for plane-to-plane bombing, (7) fragmentation and antimatériel bombs of various sizes, and (8) large chemical bombs of 500-, 1,000-, and 2,000-lb sizes.

The military requirements for these bombs were as follows:[4,5]

1. Adaptation to use in existing bombs, and to fit and drop in existing bomb racks.
2. Strength enough to withstand handling and shipping and, unarmed, drop safely on normal ground from 8,000 ft.
3. No deterioration from storage at temperatures from —40 to +140 F.
4. A minimum of adjustment and assembly in the field.
5. A design which minimizes the possibility of triggering the fuze by enemy interference.
6. Suitability for day or night use.
7. Efficient operation at temperatures from —40 to +140 F.
8. Efficient operation when released at any indicated airspeed above 150 mph.
9. Efficient operation when released from altitudes up to 35,000 ft.
10. A minimum of 1,500 ft to arm.
11. Consideration in design toward evolving a minimum number of fuze designs of suitable performance necessary to meet the requirements of various sizes and types of bombs and targets.

Burst heights were specified for only two of the foregoing applications, the T-40 and T-43 fuzes for the 10,000- and 4,000-lb LC bombs.[3] These heights were to be between 40 and 100 ft, with the mean preferably near 50 ft. This was believed to be the best height of operation for enhanced blast effect from these large high-charge bombs. The T-40 and T-43 were to be tail fuzes. The sensitivities or operating heights of the T-50 and T-51 fuzes intended for the other applications were not defined. It was, however, informally stated that, for antipersonnel and antimatériel use, burst heights of the order of 50 ft were desired. For the chemical bombs, burst heights of the order of 500 ft were believed best. Estimates in the former case were based on theoretical computations of fragmentation effect against shielded targets.[11] The T-50 and T-51 fuzes were to be nose fuzes, interchangeable with the M-103 contact fuze.

Following the development, production, and service testing of the T-50 bomb fuzes, minor changes, based on a fuller understanding of their operational properties, were made in the requirements for arming characteristics and for burst heights. These changes led to models T-89, T-90, T-91, and T-92, which are described fully in Chapters 4 and 5.

Modifications were also requested in the T-50 type fuze to allow its use on Navy rockets,[7] the modified fuzes carrying the designations T-30 and T-2004 and differing from the T-50 mainly in arming characteristics.

Experience gained in the development of the T-50 and T-51 fuzes made it evident that the physical size of radio proximity fuzes could be reduced sufficiently to allow their use on trench-mortar shells. Theoretical computations[14] indicated that a very appreciable gain in lethal effect could be obtained by air-bursting such shells. Accordingly, the Ordnance Department requested the development of the T-132, T-171, and T-172 fuzes[10] for use on the 81-mm mortar shells. According to military requirements, these fuzes must:

1. Have a basic design also applicable to 105-mm and 155-mm mortar ammunition.
2. Fit directly into the fuze cavity of standard 81-mm mortar ammunition.
3. Have sound ballistic design, minimizing any deleterious effect on projectile drag and stability as compared with fuzing with point detonating fuzes.
4. When packaged, withstand rough handling, shipping, storage over extended periods, moisture, weather, and temperature cycles from —40 to + 140 F.
5. When unpackaged, withstand loading operations, moisture, weather, and temperature cycles from —40 to +140 F for short periods, and withstand rough handling expected under service conditions incident to firing.
6. Be provided with a cap or cover to prevent entry of mud or water into the air passage after removal of the fuzed round or fuze from its packaging, such can or cover to be removed upon withdrawal of safety pin or pins.
7. Require a minimum of adjustment or assembly in the field.

8. Function at or near optimum mean effective height on approach to ground over the range of angles of fall encountered with these projectiles.

9. Limit combined early bursts and duds to 15 per cent.

10. Not be readily affected by enemy jamming or other interference.

11. Have a secondary element capable of functioning on impact with minimum effect and independently of the primary element.

12. Operate without detrimental interaction, due to mutual interference, when fired at random from weapons spaced closely together.

13. Have an interrupted detonator-explosive train, safe against rough handling, dropping, or crushing, until properly armed by removal of safety pin or pins, acceleration of firing, and a fixed air travel.

14. Have an arming delay mechanism which will insure detonator safety up to 400 yd (tentative estimated distance) from the mortar and which will also delay fuze activation until flight characteristics of the projectiles are sufficiently stable to minimize early burst due to poor stability or action of the projectile and to permit efficient fuze operation at the target.

15. Provide means for externally checking the safe position of the arming mechanism.

16. Exhibit the above safety and operating characteristics under the following conditions: (1) temperature -40 to $+160$ F, (2) all weather conditions, and (3) night or day.

The "mean effective height" referred to in requirement (8), although not specified, was understood to be of the order of 10 ft from theoretical computations,[14] but final specifications would have to await effect field trials.

It is to be noted that the requirements for T-132, etc., are much more detailed and rigorous than those for the T-5 fuze which had been laid down three years previously. In particular, requirement (9) called for 85 per cent proper functioning of fuzes, whereas 50 per cent was allowed for the T-5.

One apparently innocuous requirement introduced for security reasons applied to all bomb and rocket fuzes developed by Division 4. This was that all vacuum tubes used in the fuzes were to *fail* at accelerations between 10,000 and 20,000g.[33] The purpose of the requirement was to restrict the use of tubes suitable for shell fuzes to that application, thereby reducing the possibility that, through recovery of dud fuzes by the enemy, shell fuzes would be copied and used against our own air forces. As shown in Chapter 3, this requirement introduced some difficulties, because design considerations for microphonic stability and for ruggedness are quite similar. Thus, in the course of developing suitable antimicrophonic tubes for use in the bomb and rocket fuzes, designs were developed which were rejected because the tubes would not fail at high accelerations. The requirement was withdrawn in the fall of 1944 (when shell fuzes were committed to battle under conditions where they might be recovered by the enemy) and thus did not apply to the mortar shell fuzes developed by Division 4.

1.2 SELECTION OF THE DOPPLER-TYPE RADIO PROXIMITY FUZE

The requirement that a fuze operate in the vicinity of target may be fulfilled by making the fuze sensitive to one of a variety of energy forms: radio, optic, acoustic, magnetic, etc. A comparison of the possibilities and limitations of various energy-sensitive devices is given in Volume 3, Chapter 2, of the Division 4 STR. Here we are concerned only with radio methods.

Among the radio types there are two general classes: active and passive. The active types generate and radiate energy and are sensitive to small amounts of energy after it is reflected from a target. Passive-type fuzes are merely sensitive to incident radio waves. In each of these general classes there are further divisions and subdivisions.

Active-type fuzes may operate by dependence on interference between the original and the reflected waves, or operation may depend on the transit time for a pulse or train of waves to travel from the fuze to the target and back to the fuze again. Interference may occur in several ways. If there is relative motion between the transmitter and the reflecting target, the reflected waves when received at the fuze

will differ in frequency from the transmitted waves (doppler effect). Interference results in a beat note equal to the difference in frequency. On the other hand, if the transmitter is frequency or phase modulated, interference with the reflected waves produces a signal which is a function primarily of the distance to the target. This principle is equivalent to that of the well-known FM radio altimeter. Pulsed or intermittent circuits to determine time or distance to target operate on essentially the same principles as the common forms of radar ranging devices.

The simplest kind of passive proximity fuze requires the target to be a source of energy. Although this requirement can be satisfied for antiaircraft fuzes of the acoustic or infrared type, it would generally not hold for radio-sensitive devices. Consequently, a passive-type radio fuze would require auxiliary transmitting equipment as part of the fire control.

In selecting an operating method for a radio proximity fuze, probably the most important consideration was simplicity. It was believed that if the fuze was too complicated, it would be impracticable on two grounds: (1) its volume would be too large to satisfy ballistic requirements, and (2) it could not be manufactured in sufficient quantities in time to be of any value. Since fuzes are expendable devices, to be used only once, an appreciably different attitude toward production was required for radio proximity fuzes than for other types of radio equipment. Furthermore, a radio fuze is a device on which no adjustment is possible during its operation, hence reliability was a requirement which could not be compromised by the manufacturing problem. Thus, it appeared imperative to keep the design of a radio proximity fuze as simple as possible but still fulfill the military requirements.

The simplest type of radio fuze is probably the passive type, but, since auxiliary fire control equipment would be needed for its use, it does not meet the general requirement for "a minimum of special equipment and training" for its operational use. Passive-type radio fuzes were, however, seriously considered and investigated until it was definitely established that the transmitters required in active-type fuzes could be built in large quantities and made to operate reliably during the flight of the missile.

Probably the simplest active-type radio fuze is the doppler type, since the transmitter in such a fuze requires no internal modulation or control circuits other than an audio-frequency amplifier. Furthermore, as is shown in detail in Chapters 2 and 3, there are sufficient design parameters available in doppler fuzes to adjust the position of operation along the trajectory of the missile approximately as desired.

All radio proximity fuzes developed by Division 4 to the stage of adaptability to large-scale production are based on the doppler principle. Chosen initially because of its simplicity, the basic method has proved adequate to meet the major military requirements. More complicated systems have been surveyed and tested briefly, but none of these appeared simple enough to reduce to a mass-production design in time to be of value.

1.3 OPERATION AND PRINCIPAL COMPONENTS OF DOPPLER-TYPE FUZES

The actuating signal in a doppler-type fuze is produced by the interference with the transmitter in the fuze of the reflected energy from a target moving with respect to the fuze. The frequency of the reflected energy differs from the original by an amount $(2v \cos \alpha)/\lambda$, where v is the velocity of the fuze in a coordinate system where the reflector is at rest, λ is the wavelength of waves radiated by the fuze, and α is the angle the velocity vector makes with the line between the missile and target. The interference or combination of the two frequencies produces a low-frequency signal equal to $(2v \cos \alpha)/\lambda$, which can be used to trigger an electronic switch. Selective amplification of the low-frequency signal is generally necessary.

It is shown in detail in Chapter 2 that the concept of interference of the original and reflected waves is analytically equivalent to a load variation on the transmitting oscillator. Hence, an r-f circuit which responds to variations in its loading will generate a target signal of frequency $(2v \cos \alpha)/\lambda$. This signal may be de-

tected in a separate mixing circuit, *oscillator diode* [OD], or by a change in some parameter of the oscillator circuit, such as grid voltage, *reaction grid detector* [RGD], or plate current, *power oscillating detector* [POD]. The designations OD, RGD, and POD are further clarified in Section 3.1.

The principal elements of a radio proximity fuze are shown in block diagram form in Figure 1. The dashed lines between the oscillator and detector indicate that the two functions may be combined.

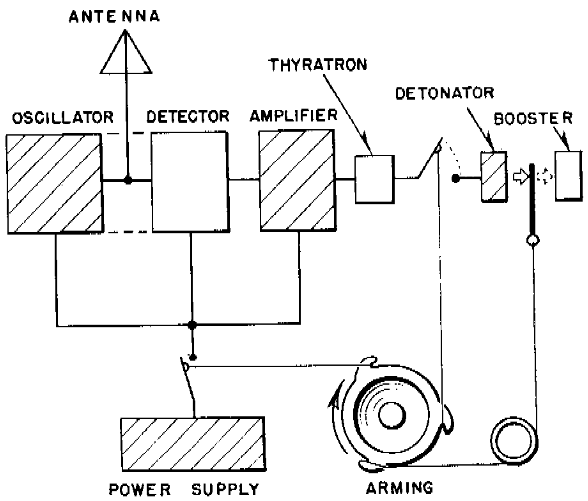

FIGURE 1. Block diagram showing principal components of radio proximity fuze, doppler type.

Operation of the fuze occurs when the output signal from the amplifier reaches the required amplitude to fire the thyratron. For a given orientation of the fuze and target, the amplitude of the target signal produced in the oscillator-detector circuit is a function of the distance between the target and the fuze. Hence, by proper settings for the gain of the amplifier and the holding bias on the thyratron, the distance of operation may be controlled. Distance, however, is not the only factor which requires consideration. Orientation or aspect is very important, particularly against aircraft targets, since operation should occur at that point on the trajectory when the greatest number of fragments will be directed toward the target.

For most missiles, the greatest number of fragments are directed upon detonation approximately at right angles to the axis of the missile. The dynamic fragmentation pattern for an M-8 rocket is shown in Figure 2,[b] and its essential features pertaining to fuze design are typical of most missiles except that for higher-velocity projectiles, the side lobes are inclined forward toward the line of flight. The graph shows the *density* of the fragments per unit area of a sphere drawn about the missile as a function of the angle between the direction of the fragments and the axis of the missile. The angle θ_m represents the latitude angle along which the greatest number of fragments are directed. The three-dimensional pattern would be that obtained by rotating the curve in Figure 2A about the flight axis. The *static* fragmentation pattern of a 500-lb GP bomb is shown in Figure 2B. The dynamic pattern, obtained by the vectorial addition of velocities due to the bomb's motion and due to the explosion, would be tipped forward a few degrees.

For trajectories which would normally pass by the target without intersecting it, there will be optimum chance of damage if detonation of the missile occurs when the target makes an angle θ_m with the missile. However, for trajectories which would intersect the target, the missile should come as close to the target as possible before detonation. Hence, the basic requirements for directional sensitivity of a proximity fuze for antiaircraft use are (1) the sensitivity should be a maximum in the direction corresponding to maximum lateral fragmentation density of the missile, and (2) the sensitivity should be a minimum along the axis of the missile. Directional sensitivity of this type can be obtained by using the missile as an

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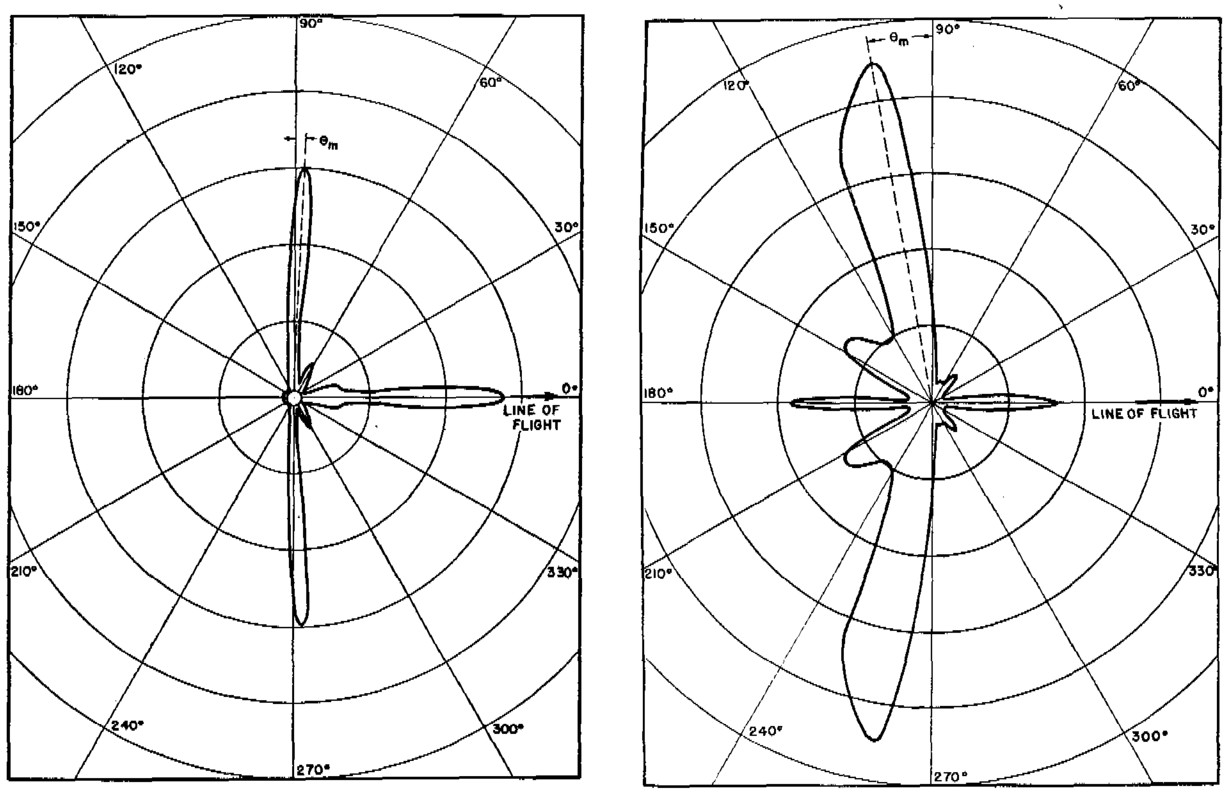
[b] It was erroneously assumed during the development of the T-5 fuze and in the absence of experimental data that the latitude (dynamic case) of maximum fragment density for the M-8 rocket would lie between 60 and 70 degrees. Actually the density of lethal fragments in this direction is greater than shown in Figure 2A because the contribution of the relatively low-velocity fragments from the rocket body are not shown in the figure. For high-velocity missiles, such as antiaircraft shells, the component of velocity due to the shell's forward motion gives a very appreciable forward tilt to the dynamic fragmentation pattern. Also, in the case of *higher-velocity aircraft rockets* [HVAR] such as the 5-in. HVAR, the latitude of maximum fragmentation density is about 66 degrees. Fuzes for this rocket (T-30) were developed later in World War II.

antenna with the axis of the missile corresponding to the axis of the antenna. With the fuze in the forward end of the missile, such antennas are end-fed by means of a small electrode or cap on the nose of the fuze. Additional control over the sensitivity pattern of the fuze is possible by means of the amplifier gain characteristic. As pointed out previously, the frequency of the target signal is $(2v \cos \alpha)/\lambda$. The angle α varies rapidly as the missile passes the target, and if maximum gain occurs when $\alpha = \theta_m$ there will be greater likelihood that the missile will be detonated at the proper point on its trajectory. More detailed discussion of these features is given in Sections 2.8 and 2.11 and in Sections 3.2 and 3.5.

For use against surface targets, proximity fuzes are designed for an optimum height of burst, depending on the nature of the target and the properties of the missile. When fragmentation bombs are air burst, the possible damage to shielded targets is substantially increased. Figure 3 shows a cross-sectional view of a typical shielded target: a man in a foxhole. The man is shielded from fragments from any bomb detonating either side of the hole and below the dashed lines. The angles ϕ_R and ϕ_L, which the lines make with the horizontal, are called the shielding angles for the respective directions. It is thus seen that, as the ϕ's increase, higher burst heights will be necessary to expose the targets. An upper limit on



A B

FIGURE 2. Fragmentation patterns of missiles.

The amplitude represents the relative density of the fragment as a function of the latitude angle around the axis of the missile. Figure 2A is for the M-8, 4.5-in. rocket and shows the dynamic pattern; i.e., directional allowance has been made for the effect of the velocity of the rocket. The graph, which is based on data in reference 19, does not include the contributions of fragments from the rocket motor. The latter are large, slow-moving, relatively few in number, and add to the pattern shown in the region between 45° and 90°. Figure 2B is a static pattern for the M-43, 500-lb GP bomb and is based on data in reference 11. The effect of bomb velocity on fragment direction is very slight (due to the relatively low velocity of the bomb) and would shift the maximum of the pattern forward of the order of 5°.

burst height is set by the lethal range of the bomb fragments since these fragments lose velocity rapidly as they travel from the point of explosion. Hence, the height of an air burst should be great enough to expose an appreciable number of targets but not so high that the fragments will be impotent when they strike the targets.

Most computations and evaluation tests for the optimum height of air burst for bombs have been on the basis of a 10° shielding or safety angle.[c] The optimum height varies only

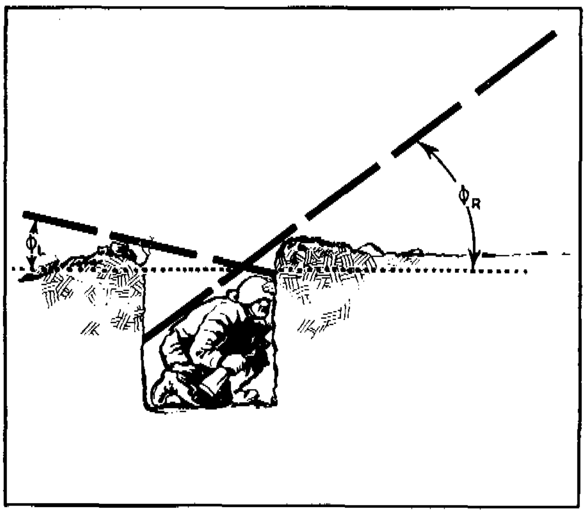


FIGURE 3. Sectional view of a soldier in foxhole, typical shielded target. Soldier is protected from fragments from explosions below dashed lines. Angle these lines make with horizontal are called shielding, or safety, angles.

slightly for the various striking angles and velocities with which bombs may approach the ground. Hence, it is desirable to design a fuze for ground-approach use which will give essentially constant burst heights for the various approach conditions.

An approach to this requirement is to have maximum radio sensitivity along the axis of the bomb, with essentially constant sensitivity to about 45 degrees on either side of the axis. (For most release conditions used operationally, bombs strike the ground with an angle to the vertical of less than 45 degrees.) A short dipole antenna mounted transversely to the bomb's axis and on the nose of the bomb essentially meets this requirement. In addition, it is necessary to design the amplifier of the fuze to give constant amplification for the range of doppler frequencies which might be encountered because of various approach velocities.

On the other hand, it was found that fairly good ground-approach performance could be obtained with fuzes with axial antennas by designing the amplifiers to compensate for the appreciable decrease in radiation sensitivity in the forward direction. For example, steep angles of approach in general mean high approach velocities with higher doppler frequencies. Thus, a loss in radiation sensitivity with steep approach can be compensated by an increase in amplifier gain for the higher doppler frequency. Details of such design are given in Section 2.2.

A miniature triode is used for the oscillator in the fuze and a pentode for the amplifier. When a separate detector is used, a tiny diode provides the required rectification. A miniature thyratron serves as the triggering agent and a specially developed electric detonator initiates the explosive action. Details concerning the design of these elements are presented in the various sections of Chapter 3.

Energy for powering the electronic circuits is obtained in the later fuze models from a small electric generator. This is driven by a windmill in the airstream of the missile. A rectifier network and voltage regulator are essential parts of the power supply. Design details of the generator power supply, as well as earlier battery power supplies, are given in Section 3.4.

The arming and safety features of the radio proximity fuzes are closely tied in with the power supply. This is a natural procedure since an electronic device is inoperative until electric energy is supplied. Arming a radio proximity fuze (generator type) consists of the following operations: (1) either (a) removal of an arming wire which frees the windmill, allowing it

[c] See references 11, 12, and 13 for theoretical values and reference 16 for effect field tests. It should be pointed out that the size of the elementary target is a primary consideration in the computation of optimum burst heights. From this point of view, overhitting on targets of finite size is decreased as the burst height increases. Thus, an optimum burst height is determined by the lethal range of fragments on the one hand and a height where overhitting becomes excessive on the other.

to turn in the airstream (bomb fuzes) or (b) actuation of a setback device freeing the drive shaft of the generator and allowing it to turn (rocket and mortar-shell fuzes), (2) operation of the generator to supply energy to the fuze circuits, (3) connection of the electric detonator into the circuit after a predetermined number of turns of the vane corresponding to a certain air travel, and (4) removing a mechanical barrier between the detonator and booster prior to which explosion of the detonator would not explode the booster. Generally, operations (3) and (4) occur simultaneously by motion of the same device.

Additional safety is provided by the fact that unless the generator of the fuze is turning rapidly the fuze is completely inoperative. A minimum airspeed of approximately 100 mph is required to start the generator turning. Details of the arming system are given in Chapter 4.

1.4 PRODUCTION OF PROXIMITY FUZES

The course of the development of radio proximity fuzes for fin-stabilized missiles and the actual nature of the devices placed in production for Service use were influenced by many factors other than fundamental technical considerations. Time and expediency had a major influence on all designs. In order to have fuzes available for use as soon as possible, tooling for large production was frequently started before development was complete. This meant that when further development indicated certain design changes to be imperative or desirable the extent of the changes which were made was controlled by the degree of the changes required in tooling or by the amount of time which would be lost by making the changes. Furthermore, no components could be included in the design which would take too long to acquire in the necessary quantity nor could production techniques be considered which were over-elaborate and time consuming.

Specific Service requirements varied as the course of World War II changed, and, because of the pressing demand for speed, fuze designs for the new requirements made much more use of the tools and techniques employed in preceding models than if production had started out fresh. For example, the greatest urgency early in World War II was for antiaircraft weapons, and stress was placed on fuzes for both bombs and rockets for this purpose. When the Allies acquired undisputed air superiority, the major proximity fuze requirements were shifted to the ground-approach operation. Thus, the T-50 type bomb fuze, which employs the axial radio antenna, ideal for antiaircraft use and initially designed for that purpose, was adapted to ground-approach use. The T-51 fuze, which employs the transverse antenna specifically developed for ground-approach use, was used much less extensively for this application because its initial lower priority made it available later in World War II.

More detailed information relating to the sequential development of radio proximity fuzes is given in the history of Division 4. The subject is mentioned here only to emphasize that the technical phases of the development were not always controlled by straightforward engineering design considerations.

After the operation of a fuze design was found satisfactory by laboratory and field tests, it was necessary to determine its practicability for mass production. Pilot construction lines were used for this purpose, and it was the policy of Division 4 to require the construction of about 10,000 pilot-line fuzes with suitable performance characteristics before releasing a design to the Armed Services. Usually the tools developed for the pilot-line work were used also for final production. Large-scale procurement was handled by the Services, but Division 4 participated in many phases of it, largely in an advisory capacity. The various technical aspects involved in the production of radio proximity fuzes are presented in Chapter 6.

The radio proximity fuzes developed by Division 4 to the stage of large-scale production are as follows. More detailed information concerning the characteristics of these fuzes is given in Chapter 5.

M-8 Rocket Fuzes

1. T-5, an antiaircraft battery-powered fuze for the 4.5-in. M-8 rocket. This fuze is shown in

Figure 4. Approximately 370,000 were procured by the Army.

2. T-6, a ground-approach fuze, for use as an artillery weapon on the 4.5-in. M-8 rocket. This fuze is a variation of the T-5, having a longer

FIGURE 4. Radio proximity fuzes for rockets. These are from left to right: (1) T-5 fuze for 4.5 in. M-8 rocket for air-to-air use (T-6 ground-to-ground fuze is identical in appearance to T-5); (2) T-2004 fuze for 5-in. AR rocket for air-to-ground use; and T-2005 multiple-purpose fuze.

arming time, about 6 sec compared to 1.0 sec, and no SD element. It is identical in exterior appearance to the T-5. Approximately 300,000 of the T-5 fuzes were converted after completion to T-6 fuzes.

3. T-12, a generator-powered fuze for use on the M-8 rocket. This fuze was not placed in large production primarily because of curtailment in requirements for the M-8 rocket.

Bomb Fuzes

1. T-50-E1, a generator-powered ground-approach fuze for use primarily on the 260-lb M-81 fragmentation bomb, the 100-lb M-30 GP bomb, and the 2,000-lb M-66 GP bomb. This fuze, which uses the bomb as a radio antenna, was planned for air-to-air use when development started but was changed to ground-approach application before development was completed. Its radio transmitter operates in the Brown frequency band. This fuze was set to arm after 3,600 ft of air travel. It is shown in Figure 5.

2. T-50-E4 is similar to the T-50-E1 fuze except that its transmitter operates in a different frequency band (White band), giving optimum performance on the 500-lb M-64 and the 1,000-lb M-65 GP bombs. Approximately 130,000 T-50-E4 and T-90 fuzes were procured by the Army.

3. T-89, an improved T-50-E1 type fuze, giving more uniform burst heights. It also differs from T-50-E1 in that arming setting can be checked more readily in the field. Approximately 140,000 T-50-E1 and T-89 fuzes were procured by the Services. This fuze is similar in appearance to the T-91 fuze, shown in Figure 5.

4. T-91 (later designation, M-168), a variation of the T-89, developed specifically to meet a naval requirement of higher burst heights than the T-89 for low-altitude bombing. This fuze is set to arm after 2,000 ft of air travel. Approximately 120,000 T-91 fuzes were produced.

5. T-92, a variation of the T-90 developed to meet the same performance requirement as the

FIGURE 5. Radio proximity fuzes for bombs. These are, from left to right: (1) T-50-E1 fuze for air-to-ground use on M-30 and M-81 bombs; (2) T-91 fuze, a later and improved version of T-50-E1, for use on M-30, M-81 and M-64 bombs; (3) T-51 fuze, air-to-ground use, for use on all bombs of 100-lb size or larger; and (4) T-82 fuze for use paralleling T-51.

T-91 of higher burst heights in low-altitude bombing. It is similar in appearance to the T-91 fuze. Approximately 70,000 were produced.

6. T-51 (later designation, M-166), a generator-powered bomb fuze with a transverse antenna for ground-approach use on all GP, fragmentation, and blast bombs of 100-lb size

or larger. Burst heights with the T-51 are generally higher than with T-50 type fuzes. This fuze was set to arm after 3,600 ft of air travel. Approximately 350,000 were procured by the Services.

7. T-82, a generator-powered bomb fuze with transverse antenna of somewhat different physical dimensions than the T-51. It was developed for the same general purpose as the T-51, but, when success of the latter was assured, further development of the T-82 was turned over to the Army.[8] It had not reached the production stage at the time of the transfer.

Later Rocket Fuzes

1. T-30 (Navy designation, Mk-171), a generator-powered rocket fuze for air-to-air use, particularly on the Navy's HVAR and the 5-in. *aircraft rocket* [AR]. This fuze is physically very similar to the T-91 bomb fuze and only slightly different electrically. Its arming system is different in that the acceleration of the rocket is essential to its operation. This fuze had just reached a production rate of 10,000 per month at the end of World War II.

2. T-2004 (Navy designation, Mk-172), a generator-powered rocket fuze for ground-approach use. It is similar to the T-30, but is somewhat less sensitive and has a longer arming time. Approximately 110,000 were procured by the Services. A photograph is shown in Figure 4.

3. T-2005, a miniature generator-powered rocket fuze for either antiaircraft or ground-approach use (by a change-over switch). It is similar electrically to the T-30 and T-2004. Development of this fuze was initiated by Division 4 but turned over to the Army for further work before the point of large-scale production was reached. A photograph of the fuze is shown in Figure 4.

Trench-Mortar Fuzes

1. T-132, a generator-powered ground-approach fuze for use on the 81-mm trench-mortar shell. This fuze, shown in Figure 6 along with the T-171 and T-172, uses the body of the shell as an antenna. It also incorporates a novel production technique, i.e., printed or stenciled electric circuits. Tools were being set up for a production rate of approximately 100,000 per month when World War II ended.

2. T-171, a generator-powered ground-approach mortar-shell fuze, similar to the T-132

FIGURE 6. Radio proximity fuzes for trench mortar shells. These are, from left to right: (1) T-132 fuze using electric circuits "printed" on ceramic plates; (2) T-171 fuze, electrically similar to T-132 but with standard electrical resistor and condensers; and (3) T-172 fuze with loop antenna.

except that it employs the more standard circuit-assembly techniques. Tools were being set up for production rate of about 125,000 per month when World War II ended.

3. T-172, a generator-powered ground-approach mortar-shell fuze with a loop antenna. This antenna has essentially the same directional properties as the transverse antenna of the T-51 bomb fuze. Tools were being set up for a production rate of about 250,000 per month.

Development of the T-40 and T-43 bomb tail fuses (referred to in Section 1.2) for the 4,000- and 10,000-lb blast bombs was not completed because the T-51 nose fuze appeared to be adequate to meet all the requirements. As shown in Chapter 9, tests of the T-51 fuzes (with minor modifications) on M-56 (4,000-lb) bombs gave excellent performance. No 10,000-lb bombs were made available for field tests.

1.5 GENERAL EFFECTIVENESS OF PROXIMITY FUZES

Although the final answer on the effectiveness of a new military weapon is supplied by

its performance in battle, the best quantitative measure of relative effectiveness under controlled conditions can be obtained from carefully planned field trials. A number of evaluation tests have been carried out on radio proximity fuzes. These can be grouped into the following categories.

1. Evaluation of conformance to requirements.
2. Evaluation as a weapon:
   a. Antiaircraft use (fragmentation effect).
   b. Air burst (ground approach on fragmentation bombs and rockets).
   c. Air burst on blast bombs.
   d. Air burst on chemical bombs.
   e. Air burst on fire bombs.

Most of the tests conducted by Division 4 other than strictly developmental tests were in the first category above. The Services also carried out extensive tests in the first category but generally after the fuzes were in production.

Tests and evaluation studies in category 2 above were usually carried out by the Services or by other NDRC divisions and therefore are not properly within the scope of this volume. The results, however, are of interest in giving a more complete picture of the evaluation of radio proximity fuzes and accordingly will be referred to briefly. Such evaluations, of course, depend primarily on the properties of the missile which carry the fuzes and in no cases were the missiles designed for proximity operation. Now that proximity fuzes have been established as practicable devices, certain missiles, such as fragmentation bombs for air-burst use should be redesigned to increase greatly their effectiveness as weapons.

Typical missiles equipped with proximity fuzes are shown in Figure 7.

1.5.1 Evaluation of Conformance to Requirements

Detailed evaluations of the conformance of the fuzes to the military requirements are presented in Chapters 5 and 9. In this section, a brief abstract is given of the most important results for production fuzes. Generally, the reliability of the radio proximity fuzes for bombs and rockets was about 85 per cent, that is, 85 per cent of the fuzes would be expected to function on the target as required. Of the remainder about 10 per cent could be expected to function before reaching the target (random bursts) and 5 per cent not to function at all. The 10 per cent or so random functions were distributed along the trajectory between the end of the arming period and the target. In many thousands of tests, no fuze functions were observed before the end of the arming period.

FIGURE 7. Radio proximity fuzes on typical missiles. These are, from bottom to top: (1) T-132 fuze on 81-mm M-56 mortar shell; (2) T-91 fuze on M-81-A 260-lf fragbentation bomb; (3) T-51 fuze on the M-64, 500-lb general purpose bomb; and (4) T-2004 fuze on 5-in. HVAR rocket.

General reliability and proximity sensitivity (function heights) for the various production models follow.

1. T-5 Fuze. Acceptance tests on over 4,000 T-5 fuzes against a mock airplane target showed the following results:
   a. 81 per cent proper functions in the vicinity of the target.
   b. 2 per cent functions just beyond the target.
   c. 13 per cent early functions between arming and the target.
   d. 4 per cent duds.

The time of flight in normal acceptance tests (see Chapter 8) was inadequate to allow test-

[redacted]

ing of the SD feature. Separate tests on the SD showed it to be 96 per cent reliable at an average time of 8.5 sec after firing. Ninety per cent of the SD functions were between 6.5 and 11 sec. These figures refer to the mechanical SD (see Chapter 4) used in later models. An electric SD used in earlier models (see Section 3.3) was less reliable.

The vicinity of the target was defined as within a 60-ft impact parameter of an 0.8-scale target of a medium bomber. For more detailed discussion of a proper definition of "vicinity of the target" see Section 1.5.2.[19-21]

2. T-6 Fuze. The percentage of proper functions for the T-6 ground-approach fuze depends on the time of flight of the rocket, the number of random functions increasing with the longer trajectories. For maximum range, tests on over 1,500 rounds indicated the following performance.

a. 80 per cent proper functions.
b. 16 per cent random functions.
c. 4 per cent duds.

Proper functions were defined as operation between 6 and 100 ft above ground.

3. T-50-E1 and T-89 Fuzes. Acceptance tests on 100 lots (lots averaged about 1,000 fuzes and field tests were made on about 18 fuzes from each lot) of T-50-E1 and T-89 bomb fuzes showed

a. 83 per cent proper functions.
b. 13 per cent random functions.
c. 4 per cent duds.

Proper functions for ring-type bomb fuzes (axial antennas) were defined as between 6 and 100 ft over a water target. The average burst height was 33 ft.

4. T-91 Fuzes. The first lots of T-91 bomb fuzes were about the same quality as the T-50-E1 fuzes. However, later lots (T-91-E1 using the RGD circuit, see Section 3.1) showed the following average for 27 lots.

a. 92 per cent proper functions.
b. 7 per cent random functions.
c. 1 per cent duds.

The average height of function was 60 ft over a water target.

5. T-50-E4 and T-90 Fuzes. Tests on 130 lots of T-50-E4 and T-90 bombs showed

a. 78 per cent proper functions.
b. 19 per cent random functions.
c. 3 per cent duds.

The average height of function was 40 ft.

6. T-92 Fuzes. Tests on 50 lots of T-92 bomb fuzes showed

a. 58 per cent proper functions.
b. 34 per cent random functions.
c. 8 per cent duds.

The average height of function was 34 ft.

The inferior performance of T-92 fuzes was due to unusual dependence of the fuze on the electric properties of the test missile, the M-64 bomb. It was found that, on bombs which had been carefully prepared to reduce variable contact between the fin and the bomb body, scores equal to those with other fuzes were obtained. When it was definitely established that the poor performance of the T-92 was due to this cause and consequently could not be improved by more rigorous production control, further procurement was terminated. It had meanwhile been shown that the T-51 and T-91 fuzes, which had become available, would fulfill the applications for which the T-92 was intended.

7. T-51 Fuzes (M-166). Field tests on 230 lots of T-51 bomb fuzes showed

a. 91 per cent proper functions.
b. 9 per cent random functions.
c. 1 per cent duds.

The average height of function over the water target was 110 ft. The proper function range included heights up to 200 ft for bar-type fuzes.

8. T-2004 Fuzes. Field tests on 75 lots of T-2004 rocket fuzes showed

a. 94 per cent proper functions.
b. 3 per cent random functions.
c. 3 per cent duds.

The average height of the proper functions was 30 ft.

1.5.2 Evaluation as a Weapon

ANTIAIRCRAFT USE

A careful analysis of the T-5 fuze on the M-8 rocket as an antiaircraft weapon was made by the Applied Mathematics Panel [AMP].[19-21] The study was based on the experimental performance of the fuze against a mock aircraft target, fragmentation data of the rocket, dis-

persion data on the rocket when fired from an airplane, and vulnerability of a twin-engine enemy aircraft, in particular the JU-88, to fragmentation damage.

Conclusions of these studies were as follows:

1. When fired from 1,000 yd directly astern with a standard deviation in firing error of about 50 ft (17 mils), a single round has one chance in 10 of preventing a twin-engined bomber from returning to base provided it cannot return to base on one engine.

2. If return to base on one engine is possible, there is one chance in 16 that a single round will prevent its return.

3. If a delay of about 50 ft were incorporated in the fuze, to bring the vulnerable part of the target in a region of greater fragmentation density, the above probabilities would be increased to 1 in 4 and 1 in 6.

The greater effectiveness of the weapon with the delay was due to the fact (as shown in Figure 2) that the latitude of greatest fragmentation density of the rocket was approximately at right angles to the axis of the rocket, whereas the fuze, as shown in Chapters 2 and 3, had been designed from an assumed latitude of maximum density of about 70 degrees. A delay of the amount recommended in the AMP report would have brought the target in the region of maximum fragment density. Such a delay could have been incorporated readily in the fuze had the tactical demand for this weapon in 1944 been as high as it was in 1942. However, there appeared to be little likelihood that M-8 rockets would be used as air-to-air weapons, so the fuzes were not modified.

The probability of obtaining a crippling direct hit by an M-8 fired under the same conditions is about 1 in 100.

Limited tests and evaluations were made of the 5-in. AR and HVAR equipped with T-30 fuzes as antiaircraft weapons. At the Naval Ordnance Test Station at Inyokern, California, some 70 rounds were fired from a fighter airplane at a radio-controlled plane in flight.[18] At about 400-yd range, over 55 per cent of the rounds functioned on the target. Eight high-explosive [HE] loaded rounds were fired, four of which functioned on the target, and three of the four destroyed the targets. Presumably, most of the rounds which did not function on the target were beyond the range of action of the fuzes.

The Applied Mathematics Panel made an informal study of the effectiveness of AR and HVAR equipped with proximity fuzes.[22] For these rockets it was found, presumably because of their higher velocities, that the optimum burst surfaces were inclined forward from the equatorial plane of the rocket and not at right angles to it, as was the case for the M-8 rocket. No experimentally determined burst surface patterns were obtained for T-30 fuzes but, assuming the same burst pattern as for T-5 fuzes, the effectiveness was nearly optimum. For example, the probability of destroying an aircraft with an HVAR with a firing error of 25 mils at 1,000-yd range was 0.4, and with 15 ft optimum delay was 0.63. Further details are in the AMP report.

Air Burst for Ground Targets

The Army Air Forces [AAF] carried out extensive evaluations of the effectiveness of air-burst bombs against shielded targets using T-50 and T-51 fuzes on M-81 (260-lb fragmentation) and M-64 (500-lb GP) bombs. Bombs were dropped on a large effect field covered with target boards 2x6 in. in trenches 1 ft deep. For equivalent airplane loads of properly functioning bombs dropped on 12-in. deep trench targets, conclusions from the AAF report are:[16]

1. Air-burst 260-lb M-81 fragmentation bombs and 500-lb M-64 GP bombs produce about 10 times as many casualties as contact-burst 20-lb M-41 fragmentation bombs when trenches are 15 ft apart. (A casualty is defined as one or more hits per square foot, capable of perforating ¾ in. of plywood.)

2. Optimum height of burst for maximum casualty effectiveness is between 20 and 50 ft, with only slight variation through this range.

The British carried out similar appraisals, using T-50 fuzes on M-64 bombs.[26] There are several differences in details of the tests, particularly in the matter of evaluating the effectiveness of surface-burst bombs. The British Ordnance Board made an appreciable allowance for the blast effect of both the contact-

fuzed bombs and variable-time [VT] fuzed bombs and arrived at a superiority factor of 4 to 1 for the latter against shielded or entrenched targets.

The AAF also evaluated the M-8 as an air-to-ground weapon with both VT (T-5) and contact fuzing.[17] The summary report concluded that the weapon was relatively ineffective against shielded surface targets, although the casualties per round with VT fuzing were about five times as high as with contact fuzing.

Air Burst for Blast Bombs

Studies by Division 2, NDRC,[23] and by the British[25] demonstrated that when large blast bombs are air burst at about 50 to 100 ft above ground, the area of demolition could be increased from 50 to 100 per cent. No full-scale tests were carried out to verify these conclusions, but it was established that the T-51 fuze could be used on both the 4,000-lb (M-56) American bomb (Chapter 9) and the 4,000-lb British bomb[27] to give air bursts at the proper altitudes.

In cooperative tests by the Army, Division 4 and Division 2, NDRC,[24, 34] it was shown that air-burst bombs could be used in mine-field clearance. The advantages were primarily in increased reliability of clearance and absence of cratering. However, the use of air-burst bombs for this purpose does not markedly reduce the number of bombs required to clear an area.

Air Burst for Chemical Bombs

A number of evaluations were made to determine the effectiveness of air bursts on chemical bombs. In a carefully planned effect field test using T-51 and T-82 fuzes on 500-lb LC bombs, the British showed the areas of contamination with a mustard-type gas were 4 to 5 times greater than when the bombs were used with contact fuzes.[30] The increase was due to a more uniform distribution of the vesicant and avoidance of loss of material in craters.

The Chemical Warfare Service and the British cooperated in an extensive series of tests at Panama in simulated jungle warfare. A T-51 fuze with reduced sensitivity effectively produced air bursts of chemical bombs below tree-top canopies with efficient distribution of chemical materials.[28, 29]

Air Burst for Fire Bombs

The Army Air Forces evaluated the effectiveness of T-51 fuzes on fire bombs and found that for high-altitude bombing the distribution of incendiary material was appreciably improved. In this application, the gain due to an air burst was due to the elimination of loss of material in craters.[31]

1.5.3 Operational Use of Proximity Fuzes

Proximity fuzes for bombs and rockets saw very limited operational use, primarily because they were introduced into action very late in World War II. Some of the factors which impeded their initial operational use are discussed in the history of Division 4. Other factors, as well as a full summary of their use in World War II, are given in a memorandum by a member of the VT Fuze Detachment of the Ordnance Department.[32] Some excerpts from the latter reference are given in Chapter 9.

Altogether, approximately 20,000 fuzes, primarily bomb fuzes, were used in action by the Army and the Navy in the Pacific, and in the European and Mediterranean Theatres of Operation [ETO] and [MTO]. In the last few weeks of the war in the Pacific, approximately one-third of all bomb fuzes used by carrier-based aircraft were proximity fuzes. The main targets were antiaircraft gun emplacements and airfields.

No thoroughgoing analysis of the effectiveness of the fuzes operationally was possible, although the general reaction was very favorable. Since the fuzes were used in all theaters so late in World War II, the major uses were of a trial or introductory nature. In all cases, these trial uses were followed by urgent requests for more fuzes, which usually, and particularly in ETO and MTO, did not arrive until after World War II was over. All initial uses were in 1945, in February in the Pacific and in March in ETO and MTO. Reports concerning the effectiveness of the fuzes against gun emplacement targets generally stated that antiaircraft fire was either stopped or greatly re-

duced after the air-burst bombs exploded.

Although relatively little or no quantitative data as to the effectiveness of the fuzes was secured, their use was extensive enough to establish their practicability as service items of ordnance equipment. Relatively little difficulty was experienced in the handling and use of the fuzes and none of these was serious or insurmountable. Hence, with the effectiveness of proximity fuzes well established by effect field studies and operational practicability established by combat use, proximity fuzes appear assured of a permanent and increasingly important position in modern ordnance. The technical information presented in the succeeding chapters of this volume not only serves to provide a full understanding of the properties of the fuzes which were developed and produced, but it also provides a firm and logical basis for future development.

Chapter 2

THE RADIATION INTERACTION SYSTEM[a]

2.1 INTRODUCTION

THE PRECEDING CHAPTER has explained what a proximity fuze is and has shown what the fuze must do by stating the military characteristics required for such a device. The basis upon which the radio reflection principle was selected as most suitable for a proximity fuze has been discussed, and some of the reasons for using the doppler principle have been presented. We are now in a position to explain the working principles of the device and its engineering design.

In discussing the working principles we are concerned with two essentially independent sets of phenomena: (1) those external to the fuze mechanism, i.e., the emission and reception of radiation and its interaction with the target; and (2) those within the fuze itself, i.e., internal circuit behavior.

The present chapter deals with the first group, external phenomena, which we call the radiation interaction system. To facilitate discussion, an arbitrary dividing line is drawn at the point where the internal fuze circuit is electrically connected to the fuze antenna. As will be seen, it is possible to describe the external phenomena so that their effect can be expressed as an appropriate variation of impedance at these antenna terminals. When the relation between the radiation interaction with the target and the variation of antenna impedance has been determined, the problem becomes one of constructing a practical circuit which will respond properly to the changes seen at its terminals.

It should not be inferred from this division of phenomena, for the purposes of discussion, that antenna design and circuit design are entirely independent. Each must be designed with due regard to the other, and both designs are dictated by such practical considerations as physical limitations of components and tactical utility. In fact it will become evident as the discussion proceeds that the working principles of the fuze are quite simple and that the real difficulty in making a practical proximity fuze lies in reaching an adequate compromise between a host of closely interrelated factors. The coordination of these various factors is treated in Section 3.5.

Many of the phenomena treated in this chapter are shown to be negligible or unimportant for the type of doppler fuzes of immediate interest. The phenomena may, however, have appreciable importance for fuzes of other types or for more extensive applications of the present fuzes. For these reasons, the basic theory has been treated in appreciable detail by developing considerable material found in advanced textbooks on radiation and circuit theory. This approach should enable new investigators in the field of proximity fuzes to familiarize themselves with the fundamental principles involved with a minimum of recourse to the technical literature.

2.2 SPECIFICATION OF PROBLEM IN TERMS OF ANTENNA IMPEDANCE

The fuze detects the presence of an obstacle in its radiation field by means of returning radiation reflected by the obstacle. The physical situation is thus characterized by an outgoing wave with a frequency determined by the fuze transmitter and a returning wave of much smaller amplitude, whose frequency may be different as a result of relative motion of fuze and reflector. In all the discussion which follows, it will be assumed that the reflecting obstacles are linear reflectors, by which we mean that the strength of the reflected field is proportional to the strength of the incident field. It is shown in this section that the returning wave differs in frequency from the outgoing wave by an amount which can be calculated by the application of the doppler principle, and that under certain conditions, which hold for present fuze designs, this combination of outgoing and reflected wave is exactly equivalent to a change

[a] By R. D. Huntoon and P. R. Karr.

in antenna impedance. The usefulness and limitations of this concept are discussed.

2.2.1 Reflected Wave or Doppler Frequency Concept

Consider a radiating system R which radiates a carrier of frequency f. Its field in any direction x will be of the form

$$E = Ae^{j2\pi f[t - (x/c)]}. \tag{1}$$

Let the radiation be received in a system R' moving with a velocity v in the direction $-x$, i.e., toward the system R. In this moving system of reference the field will be of the form

$$E' = A'e^{j2\pi f'[t' - (x'/c)]}. \tag{2}$$

The phase of the wave is relativistically invariant, so that

$$f\left(t - \frac{x}{c}\right) = f'\left(t' - \frac{x'}{c}\right). \tag{3}$$

Now t' and x' are related to t and x by the Lorentz transformation. Applying this gives

$$f' = f\sqrt{\frac{1 + v/c}{1 - v/c}} = f\left(1 + \frac{v}{c} + \frac{1}{2}\frac{v^2}{c^2}\cdots\right), \tag{4}$$

when it is remembered that v is $-dx/dt$.

At the present time relative velocity of fuze and target never exceeds 5,000 fps so that v/c is of the order of 5×10^{-6}. Equation (4) can be rewritten

$$f' = f\left(1 + \frac{v}{f\lambda} + \frac{1}{2}\frac{v}{c}\frac{v}{f\lambda}\right) = f + \frac{v}{\lambda}\left(1 + \frac{v}{2c}\cdots\right), \tag{5}$$

which is close enough to

$$f' = f + \frac{v}{\lambda}, \tag{6}$$

which is recognized to be the normal doppler frequency shift. Thus the frequency received at the target is given by equation (6) above. The target reradiates, reflects, on this frequency, and a second application of the above argument leads to

$$f'' = f + \frac{2v}{\lambda}, \tag{7}$$

where f'' is the frequency of the reflected wave as seen at the fuze. For current fuze designs, the doppler or difference frequency $2v/\lambda$ is of the order of a few hundred cycles per second out of a carrier frequency of the order of 100 mc and the error introduced by neglecting relativistic effects is of the order of 10^{-4} c.

2.2.2 Reflection Equivalent to Change of Antenna Impedance

The two-wave picture outlined above can be converted to the equivalent impedance picture quite simply. First, assume the system R' to be at rest, so that $f = f' = f''$. Then the field of the system R, equation (1), can be written as

$$E = KIe^{j2\pi[ft - (x/\lambda)]}, \tag{8}$$

where the dependence of E upon I, the antenna current, is shown explicitly. This field is reflected from the target at distance x with a loss in amplitude and a phase shift δ and returns as reflected field E_r, given by

$$E_r = BKIe^{j2\pi[ft - (2x/\lambda) + \delta]}. \tag{9}$$

The constant B represents the loss at reflection and represents also the initial assumption that reflected field is proportional to incident field. The fuze antenna receives this reflected field E_r and converts it to a voltage V_r so that

$$V_r = B'KIe^{j2\pi[ft - (2x/\lambda) + \delta]}, \tag{10}$$

showing that V_r is proportional to I, the transmitting antenna current. The term B' replaces B and now involves an additional factor translating field to voltage.

At this point it is necessary to call attention to the fact that the radio fuzes herein described and to which the theory we are discussing is applicable use a common antenna for transmission and reception and use the same terminals for transmission and reception. Thus the current I in equation (10) represents the transmitter current into the antenna terminals, and V_r represents the voltage across those same terminals arising as a result of the presence of the reflector in space. Since (V_r/I) is dimensionally an impedance, we may write

$$V_r = IZ_re^{j2\pi ft}, \tag{11}$$

where

$$Z_r = B'Ke^{j2\pi[(-2x/\lambda) + \delta]}. \tag{12}$$

The constants $B'K$ represent the magnitude of the reflected impedance Z_r, and the term $e^{j2\pi(-2x/\lambda)}$

shows the variation of the phase angle as the distance x to the target changes. In the above discussion, I has been assumed to be constant in the presence of the reflector. This assumption is made only for purposes of computing Z_r; the results obtained hold when I varies, as it normally does.

Suppose now that the target moves toward the fuze with a velocity $V = dx/dt$. Then the rate of change of total phase Φ of the impedance is

$$\frac{d\Phi}{dt} = \frac{d}{dt}\left(\frac{-4\pi x}{\lambda}\right) = +\frac{4\pi v}{\lambda}. \tag{13}$$

The frequency F with which the impedance Z_r completes its phase cycle is given by

$$F = \frac{1}{2\pi}\frac{d\Phi}{dt} = +\frac{2v}{\lambda}, \tag{14}$$

a value identical with the doppler frequency derived above, equation (7). We thus see that the reflector can be replaced in the fuze antenna circuit by a reflected impedance Z_r, whose amplitude represents the strength of the reflected voltage and whose rate of change of phase corresponds to the doppler frequency shift. In this derivation of the frequency F, we have neglected relativistic effects; these are, of course, negligible, just as in the preceding derivation.

For fuzes having a common antenna for transmission and reception, using common terminals for both, we can represent the behavior

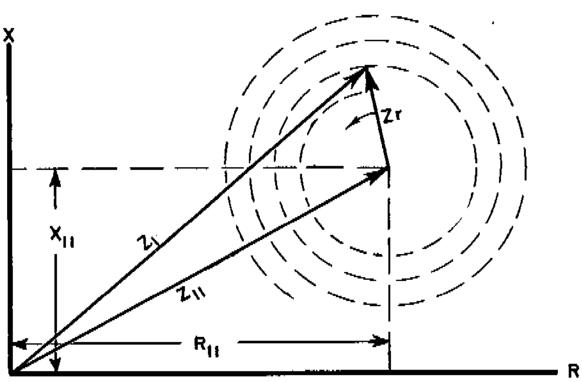


FIGURE 1. Vector representation of antenna impedance in presence of reflector.

associated with a moving reflector in the radiation field by the vector diagram shown in Figure 1.

In this figure Z_{11} represents the impedance at the antenna terminals in the absence of all reflectors (free space). Its resistive and reactive components are R_{11} and X_{11} respectively. The term Z_r represents the reflected impedance and Z_1 the total antenna impedance with the reflector present. When a target moves toward the fuze with a velocity v, the end of Z_r traces out a spirallike figure with an angular velocity

$$\omega = 2\pi F = \frac{4\pi v}{\lambda}.$$

The radius increases as Z_r increases.

2.2.3 Approximations Involved in Impedance Representation

Suppose we consider two systems, each enclosed in a box with only two terminals available to the experimenter and no indications outside to show the contents of the box. Let box 1 contain a fuze antenna, space for radiation, and a moving reflecting target. Let box 2, identical in every external detail with box 1, contain within it a fixed impedance Z_{11} and a variable impedance Z_r with magnitudes selected according to the definitions above.

In a steady-state condition, i.e., with $\omega = 0$ and with the fuze in operation long enough for all transients to die out, no set of measurements can distinguish a difference between the contents of the two boxes, and they are for all purposes identical.

If we test the two arrangements by suddenly applying the r-f voltage to the terminals, there will be a difference in the way in which the steady state is reached. This difference is analogous to the difference in the transient behavior of two circuits A and B, where B is identical with A except for a length of perfect transmission line attached to its input terminals. If a signal were suddenly applied to the input terminals of A, a certain transient response would be obtained at the output of A. If the same signal were suddenly applied to the input of the transmission line attached to B, the transient response at the output of B would differ from that at the output of A because of the delays due to the transmission line. The steady-state behavior of the two circuits, how-

ever, would be identical. Thus in the case of the fuze circuit we can apply the impedance concept, which is a steady-state concept, to those cases in which the delays associated with the radiation link are negligible. We now proceed to show that these delays are unimportant in cases of interest.

One effect of the finite transmission time of the waves is that at any time t the fuze receives a reflected signal which is characteristic of the target not at time t but at time $(t - r/c)$, where r is the distance from target to fuze at the moment when the signal which arrives at the fuze at time t started out from the target. This means that the fuze does not "know" its distance from the target at any instant, but only what the distance was at a time (r/c) in the past. In the region of interest r/c is of the order of 10^{-6} sec, during which time the fuze moves a distance of the order of 10^{-3} ft. Thus this effect is seen to be of no importance in determining the position of function of the fuze. It may be pointed out, however, that for proximity fuzes which work on other principles, for example, the reflection of radiated sound, this effect may be of considerable importance.

Another effect of the delay associated with the radiation link is that it introduces an effective "time constant" in the fuze circuit because of the effect which the reflected voltage has on the antenna voltage, which in turn influences the reflected voltage, etc. A rough estimate of the order of magnitude of this time may be obtained by assuming the fuze and antenna stationary and computing the time required for the fuze voltage to reach a steady-state value after being switched on. The time required to reach equilibrium is assumed for the purposes of this discussion to be associated entirely with the propagation of the waves in space and not at all with delay characteristics of the fuze circuit itself.

The presence of the reflector induces a voltage in the fuze proportional to the voltage induced in the reflector by the fuze antenna. The above statement can be made more precise by including the time element; that is, suppose at time $t = 0$, the fuze begins to radiate. Some of the radiation "bounces" back from the reflector, reaches the fuze again at time Δt, usually appreciably less than 10^{-6} sec, and induces a voltage in the fuze antenna. This causes a change in the radiation; this changed radiation is reflected by the target again, and its effect is felt back at the fuze at time $2\,\Delta t$. This process goes on until equilibrium is reached.

For the sake of simplicity, assume that the distance of separation is such that the impressed and reflected voltage in the fuze antenna are always in phase. In this case the effect of the reflected radiation is to increase the voltage in the fuze antenna. Let k be the constant relating the voltage induced in the fuze antenna by reflected radiation to the voltage in the fuze antenna, which was associated with the original radiation. For many cases of interest k is of the order of 0.01. Then the variation in the fuze voltage starting from $t = 0$ may be represented as in Figure 2, in which no attempt has been made to represent the true scale. In the figure V_0 represents the voltage at $t = 0$. The expression for this variation is

$$V(t) = V_0 + kV(t - \Delta t), \tag{15}$$

which applies for $t \geqslant \Delta t$. For $t < \Delta t$, $V(t) = V_0$. The equilibrium voltage V_∞ is the limit of the series

$$V_\infty = V_0(1 + k + k^2 + k^3 + \cdots), \tag{16}$$

$$V_\infty = \frac{V_0}{1 - k}. \tag{17}$$

For $k << 1$, we have

$$V_\infty \approx (1 + k)\,V_0. \tag{17a}$$

Furthermore

$$V(\Delta t) = (1 + k)\,V_0. \tag{18}$$

Thus we see that for small k the first reflection is responsible for most of the voltage change. This would be true for any other assumed phase relation between the impressed and reflected voltages in the fuze.

If desired, we may replace the stepwise variation by a smooth curve, as shown roughly in Figure 2; this smooth curve may be represented analytically. To do this we replace $V(t - \Delta t)$ in equation (15) by the quantity $[V(t) - \Delta t\,(dV/dt)]$, the first two terms of the Taylor expansion.

[redacted]

This gives us the differential equation

$$V(t) = V_0 + k\left[V(t) - \Delta t\,\frac{dV(t)}{dt}\right], \qquad (19)$$

whose solution is

$$V(t) = \frac{V_0}{1-k}\left[1 - k^2 e^{(1-k)(\Delta t - t)/(k\Delta t)}\right]. \qquad (20)$$

This equation is, of course, to be applied only for $t \geqq \Delta t$.

From equation (20) we find that

$$V_\infty = \frac{1}{1-k} V_0,$$

and

$$V(\Delta t) = (1 + k)\, V_0,$$

agreeing with the previously obtained results. The order of magnitude of the effect described above is seen to be quite negligible for the fuzes described here. This effect may, however, take on fundamental importance for fuzes operating on other principles, such as those working on acoustic or pulse-time principles.

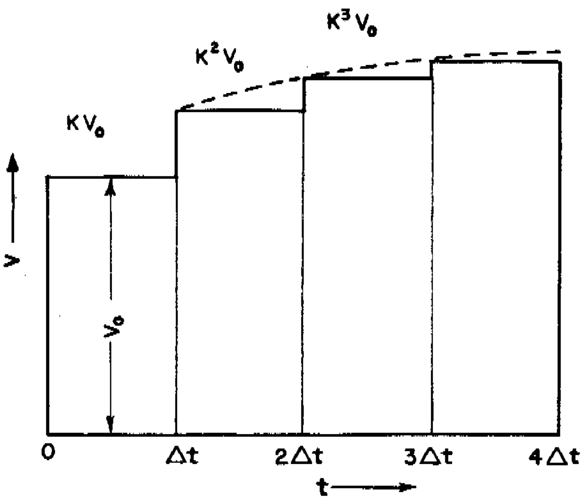


FIGURE. 2. Variation of voltage in fuze antenna; fuze and target stationary.

2.2.4 Implications of Impedance Concept

The advantage of regarding the basic effect of a reflector as an impedance change can be seen when an attempt is made to describe the phenomenon in terms of another concept which appears at first plausible, namely, the concept of the effect of the reflection as a generator e in series with the radiation impedance Z_{11}, as in Figure 3. The reflector does indeed create a voltage e in the antenna. This voltage e however, changes the current I in the antenna, *which in turn changes* e, and so on. This effect of the change in I upon e must be taken into account, and the impedance concept does this, whereas the generator concept as ordinarily applied does not do so; we do not ordinarily think of a generated voltage e as being affected by the current changes which it produces in the external circuit. Of course, in those cases in which the reflected voltage e is small enough so that its effect on I is negligible it may be treated as a generator.

Another important aspect of the impedance concept is its essentially geometric character. It will be shown by more detailed analysis in the following sections that the reflected impedance in an antenna due to the presence of a reflector is a function only of the geometric configuration, of the directive properties of the antenna, and of the character of the reflector. The power level at which the antenna radiates has no effect on the reflected impedance; this, of course, is not true of the reflected voltage. This lack of dependence of the reflected impedance upon power level implies that fuzes with widely differing power outputs can be made which have the same sensitivity to reflection. This is indeed true; fuzes have been made with radiated power outputs ranging from 1/5 mw to 1 w, with equal sensitivity to reflection. From the point of view of freedom

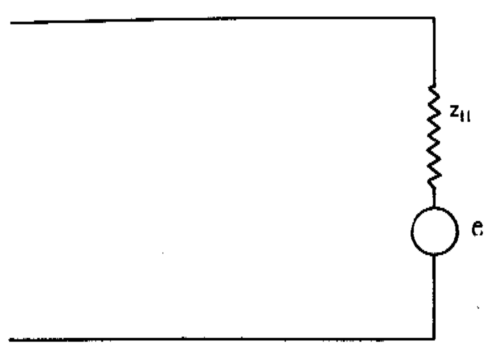


FIGURE 3. Generator e in series with fuze antenna impedance, Z_{11}.

from interference, however, it is fairly obvious that the higher power level is desirable. That is, the reflected voltage increases with the power level and therefore any extraneous radiation would have to be so much the stronger to induce, in the fuze, signals comparable in magnitude to those coming from the reflector.

2.3 MUTUAL INTERACTION OF SYSTEMS OF TWO-TERMINAL NETWORKS INVOLVING RADIATION

In the preceding section it has been shown that, with certain approximations, the effect of a reflecting target is equivalent to a change in the input impedance of the fuze antenna. To the extent that this is so, the interaction phenomena between fuze antenna and target are describable in terms of the steady-state analysis of coupled networks. The familiar concepts of mutual impedance and reflected or coupled impedance will be used. In fact the antenna impedance change to be evaluated is identical with the reflected or coupled impedance of circuit theory.

2.3.1 Fuze Problem as Interaction of Two-Terminal Networks

For fuzes of the single-antenna type, developed by Division 4, the problem of the interaction with the target reduces to that of computing the reflected impedance. The actual targets encountered by the fuze radiation may be relatively simple, as in the case of ground approach where the fuze can be considered as interacting with its image, or complicated, as in the case of an aircraft target with its complicated mode of excitation and complicated reflection pattern. In the latter case it is customary to determine performance of a fuze on the basis of its interaction with a simple target, such as a half-wave reflecting dipole, and by experiment to relate the reflection from the complicated target to that from a simple target.

Thus in the argument which follows in this section the problem will be set up on the basis of mutual interaction between a system of n simple two-terminal networks connected by radiation. In some cases one of these networks will represent the target antenna. When the theory has been worked out formally on this basis, the problem of a complicated target will be discussed in more detail.

2.3.2 Fundamental Equations

We now formulate the problem in a more precise way. Let the fuze and reflecting objects be considered as a system of antennas. If the ground is involved, we consider it as perfectly conducting and replace it by the image of each of the real antennas. For the fuze problem the fuze antenna and its image are driven; all other antennas are parasitic. If some of the other antennas are driven by appropriate generators, we are then concerned with fuze operation in the presence of interference or intentional countermeasures. This case is subject to separate treatment, which is not within the scope of this volume.

In general, if we have the fuze antenna interacting with $n-1$ additional antennas, we may set up n equations:

$$\begin{aligned}
V_1 &= I_1Z_{11} + I_2Z_{12} + I_3Z_{13} + \cdots + I_nZ_{1n}, \\
V_2 &= I_1Z_{21} + I_2Z_{22} + I_3Z_{23} + \cdots + I_nZ_{2n}, \qquad (21) \\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\
V_n &= I_1Z_{n1} + I_2Z_{n2} + I_3Z_{n3} + \cdots + I_nZ_{nn},
\end{aligned}$$

where I_j is the current in the jth antenna and V_j is the voltage impressed on the jth antenna. The set of equations (21) is a well-known way of representing the interaction between n coupled circuits or n antennas. On account of the reciprocal relations between antennas, $Z_{ij} = Z_{ji}$.

The meaning of the Z's can be elucidated quite simply. If, for example, we open-circuit all antennas except No. 1 so that all I's except I_1 are zero, we have $V_1 = I_1Z_{11}$, so that Z_{11} is the free-space impedance of antenna No. 1 and V_1 and I_1 are the free-space voltage and current, respectively. I_1Z_{21} is the open-circuit voltage of antenna No. 2 due to current I_1 in antenna No. 1. The term Z_{21} is the mutual impedance between No. 1 and No. 2. The input impedance of No. 1 in the presence of an arbitrary number of other antennas is

$(V_1/I_1) = Z_1$. When the n antennas are too far apart to influence each other, the Z_{ij}'s vanish $(i \neq j)$ leaving only the Z_{ii}'s.

As has already been mentioned, the ground is considered as a perfectly conducting plane, infinite in extent. Modifications required for an imperfectly conducting ground are considered later. It is well known that we may "remove" the ground plane and replace it by images of each of the antennas above ground. The relation of the currents in an image and a real antenna are shown in Figure 4 for two configurations. The arrows point in the direction of instantaneous current.

If the components of current normal and parallel to the surface are always as shown, the boundary conditions at the reflecting surface will be satisfied and the field of the image above the plane is identical with the reflected field.

Since each of the images contributes to the total effect on the fuze antenna, they may appreciably affect the operation of the fuze. When the target and fuze are far removed from ground, the effect of their images becomes negligible. This is essentially true of the application of the fuze against enemy aircraft in flight for fuzes as now constructed. The influence of the ground in this case will be discussed in more detail later.

To take account of the effect of the ground we include the images in the set of n equations, letting the odd numbers represent real antennas and even numbers the image antennas. Thus antenna No. 1 represents the fuze, No. 2 its image, No. 3 a real antenna, and No. 4 its image, and so on, each even number representing the image of the odd number preceding.

In the notation of equation (21) the boundary conditions will be satisfied if we put

$$I_r = -I_{(r-1)} \quad (r \text{ even}).$$

Since

$$Z_r = Z_{(r-1)},\ V_r = -V_{(r-1)}.$$

It will now be found that the odd-numbered equations from equation (21) form a complete set of $n/2$ equations to specify the solution for the $n/2$ currents in the real antennas. The remaining equations can be shown to form an identical set and so contribute nothing further.

2.3.3 Specific Fuze Equations

In the typical fuze situation only the fuze antenna is driven. In equations (21) this is represented by putting $V_1 = V$ and $V_2 = -V$ with all other $V_i = 0$. Let us consider this case and solve for V/I_1, the apparent input impedance Z_1 of the fuze antenna. As previously stated, we use only the odd-numbered equations.

A sufficiently general case which includes all

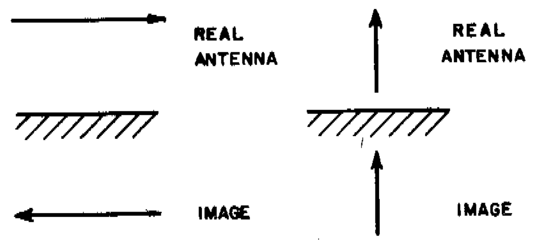


FIGURE 4. Relation of currents in real and image antennas, for horizontal and vertical cases.

fuze problems of immediate interest arises from the consideration of two real antennas and their two images. For this case antenna No. 1 is the fuze, antenna No. 2 its image, antenna No. 3 is the target, and antenna No. 4 is its image.

For this special case the appropriate equations are

$$\begin{aligned} V &= I_1Z_{11} - I_1Z_{12} + I_3Z_{13} - I_3Z_{14} \\ 0 &= I_1Z_{13} - I_1Z_{23} + I_3Z_{33} - I_3Z_{34} \end{aligned} \qquad (22)$$

where we have utilized the fact that $Z_{ij} = Z_{ji}$. By symmetry, it is clear that $Z_{23} = Z_{14}$. Incorporating this in equations (22) we get for the input impedance Z_1 of the fuze

$$Z_1 = \frac{V}{I_1} = Z_{11} - Z_{12} - \frac{(Z_{13} - Z_{14})^2}{Z_{33} - Z_{34}}. \qquad (23)$$

Equation (23) shows that the impedance of the fuze antenna is its free-space value Z_{11} plus additional terms representing the presence of target and ground. Three cases of interest arise.

Case I. Ground Approach. In this case the fuze uses the ground as a target and antenna No. 3 with its image No. 4 are absent. This means that there are no nearby reflectors except the ground. For this case $Z_{13} = Z_{14} = 0$ and Z_1 reduces to

$$Z_1 = Z_{11} - Z_{12}. \qquad (24)$$

[redacted]

The coupled impedance is the mutual impedance Z_{12} between the fuze and its image. This leads to an important concept in understanding fuze operation against the ground; i.e., in the ground-approach case the fuze can be thought of as being fired by its image. Since object and image are connected by a line normal to the plane, the vertical distance from fuze to plane is a determining factor.

Case II. Isolated Airborne Target. It is now assumed that antennas No. 1 and No. 3 are far removed from ground in comparison with their separation. This makes

$$Z_{12} = Z_{14} = Z_{34} = 0.$$

The result is

$$Z_1 = Z_{11} - \frac{Z_{13}^2}{Z_{33}}, \tag{25}$$

and the coupled impedance has the value (Z_{13}^2/Z_{33}). An interesting point should be mentioned here in connection with jamming fuzes. If antenna No. 3 represents a jammer antenna instead of a target and if Z_{33} includes some negative resistance incorporated by feedback of some sort, Z_{33} can be made much smaller than the Z_{33} obtained if the feedback is removed. Thus a negative resistance jammer will build up a signal of magnified form and may cause the fuze to function before it should normally.

Such a scheme has difficulties of realization in practice which may make it impossible.

Case III. Airborne Target with Ground Interference. In this case the full equation (23) is applicable and must be considered in some detail. If the target is not moving with respect to its image, as in the case of a test target, Z_{34} will be a constant and reasonably small compared with Z_{33}. To a good approximation we may use Z_{33} alone. Thus equation (23) includes:

1. Z_{12} representing the interaction of the fuze antenna with the ground.

2. Z_{13}^2/Z_{33} representing the interaction of the fuze antenna with the target plus two other terms of the same order as this which may lead to interference.

This is as far as the argument can proceed without detailed knowledge of the mutual and self-impedances involved. We now turn attention to the values of impedance to be expected.

2.4 ANALYTIC EXPRESSIONS FOR MUTUAL IMPEDANCE, RADIATION FIELDS ONLY

2.4.1 Basis of the Argument

We have developed above general expressions for the apparent input impedance of the fuze antenna when in the neighborhood of other antennas, among which may be included the image of the fuze antenna. These equations will now be made more specific, so that they can be applied to actual cases.[1, 4, 9]

In the argument to follow we will confine ourselves to the case of radiation fields alone, leaving the problem of correction due to induction and quasi-static components to Section 2.10. The corrections are not necessary to predict fuze operation in a large majority of cases.

By neglecting the corrections it is possible to set up a general argument which makes no assumptions about the nature of the current distribution on the fuze antenna or the mode of interaction with the reflected radiation. All we need to know about the fuze antenna is that: (1) it has two terminals for connection to the oscillator circuit; (2) when current flows through these terminals, radiation appears in the surroundings with a distribution which can be measured experimentally; and (3) the loss of energy by radiation appears as a resistance in the antenna circuit to which the oscillator is connected.

To derive the necessary expressions we will first express the field strength E of an antenna at point P in space in terms of (1) the distance r from the antenna, (2) the experimentally measured radiation pattern $f(\theta,\phi)$, (3) the gain G of the antenna as calculated from $f(\theta,\phi)$, (4) the series radiation resistance R_s, and (5) the driving point current I into the antenna terminals.

The meaning of R_s may be clarified by representing the system as in Figure 5, where the box is the fuze system which emits radiation. If we integrate the energy flow at infinity when a current I flows into the terminals, we find that a certain amount of power is carried away by radiation. If this power is W, then by definition

$$R_s = \frac{2W}{|I|^2} \quad \text{or} \quad \frac{2W}{II^*}$$

[redacted]

Now there may be other components in the box which dissipate energy. They are not included in R_s.

If we measure the input impedance at the terminals TT when the box is in free space in

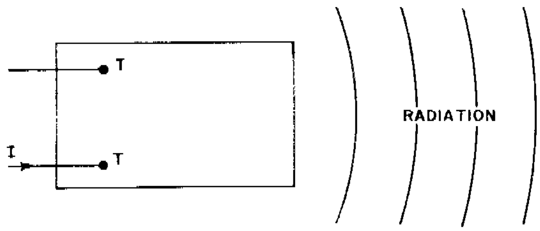


FIGURE 5. Representation of fuze system emitting radiation.

the absence of reflectors, the result is Z_{11}. When reflectors are present, the result is Z_1, as defined previously. The above definition of R_s implies that all the antenna current I flows through R_s, meaning that R_s is in series with I. Likewise the coupled impedance representing the reflector will also be in series with I. The argument upon which equations (21) are based then means that we consider the antenna as equivalent to the circuit in Figure 6. Thus $Z_{11} = R_s + R_a + jX_s$ and ΔZ represents the reflected impedance. The term R_a represents the ohmic losses in the antenna, which are quite small and will be neglected unless otherwise specified.

When the field relations have been derived, it will then be necessary to determine the response of the antenna to radiation falling upon it. This will be derived with the aid of the reciprocity theorem. The two concepts will serve to solve the fuze problem in so far as pure radiation fields are concerned.

2.4.2 Field Equations for Arbitrary Antenna

We assume a spherical coordinate system, with the origin at the center of the antenna and the antenna lying along the polar axis. The electric field strength E is a vector function of position. If we describe a large imaginary sphere around the antenna, then a plot of the field strength E, on the surface of the sphere, as a function of the polar angle and the azimuth angle ϕ is known as the space radiation pattern of the antenna. If we normalize the values of $|E|$ found around the sphere so that the maximum value is unity, the dependence on θ and ϕ is known as $f(\theta,\phi)$. The actual value of the field strength at any point (θ,ϕ) on the sphere is given by

$$|E| = E_0 f(\theta,\phi), \tag{26}$$

where E_0 is the maximum value of $|E|$ on the surface of the sphere. We assume that $f(\theta,\phi)$ has been determined experimentally (see Section 2.8).

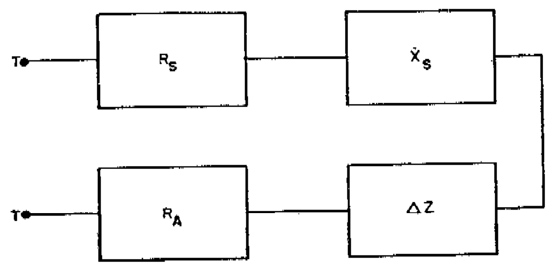


FIGURE 6. Series equivalent circuit of fuze antenna.

The power W radiated through the sphere is obtained by integrating the Poynting vector over the surface of the sphere and is given in mks units by

$$W = \frac{r^2 E_0^2}{2Z_0} \int_0^{2\pi} \int_0^{\pi} f^2(\theta,\phi) \sin \theta d\theta d\phi, \tag{27}$$

$$W = \frac{E_0^2 r^2}{2Z_0} \gamma, \tag{28}$$

where

$$\gamma = \int_0^{2\pi} \int_0^{\pi} f^2(\theta,\phi) \sin \theta d\theta d\phi,$$

and

$$Z_0 = \sqrt{(\mu/K)},$$

the "intrinsic impedance" of free space, μ and K being the permeability and dielectric constant respectively of free space, or air. The term $Z_0 = 120\pi$ ohms.

Taking into account equations (26) and (28), we write

$$E = \frac{1}{r}\sqrt{\frac{2WZ_0}{\gamma}} \left\{ f(\theta,\phi) e^{j[\omega t - (2\pi r/\lambda)]} \right\}, \tag{29}$$

where λ is the wavelength. This expression ig-

[redacted]

nores a possible additive phase shift which may be a function of (θ,ϕ). It will be introduced when needed.

We may now introduce the concept of gain of an antenna. If we compare two antennas, each of which radiates so as to produce equal values of E_0 at a given distance r, then the antenna which radiates less power has the greater gain G. An antenna for which the space radiation is spherical, i.e., one which radiates equally in all directions, has the lowest possible gain. From equation (28) we see that for two antennas, No. 1 and No. 2, with equal values of E_0 at the same value of r

$$\frac{G_2}{G_1} = \frac{W_1}{W_2} = \frac{\gamma_1}{\gamma_2}. \tag{30}$$

For an isotropic radiator $\gamma = 4\pi$. If we arbitrarily assign this antenna a gain of unity, we have for any antenna

$$G = \frac{4\pi}{\gamma}. \tag{31}$$

Typical values of G for representative antennas will be found in Figures 21 through 24.

Equation (29) may now be transformed:

$$E = \frac{1}{r}\sqrt{\frac{Z_0 W G}{2\pi}}\left\{f(\theta,\phi)e^{j[\omega t - (2\pi r/\lambda)]}\right\}. \tag{32}$$

As already indicated, we put

$$R_s = \frac{2W}{|I|^2}, \tag{33}$$

and rewrite equation (32) as

$$E = \frac{I_1}{r}\sqrt{\frac{Z_0 R_s G}{4\pi}}\left\{f(\theta,\phi) j e^{j(-2\pi r/\lambda)}\right\}, \tag{34}$$

where $I_1 = |I|\, e^{j\omega t}$. The factor j correctly relates the phase of E to that of I_1 in the case of an elementary dipole. For other antennas, there may still be an additional phase shift, as mentioned above. This is the final equation relating the field to the antenna and shows the *radiation* field as a function of position around the fuze antenna. To solve the fuze problem we need to know how this arbitrary antenna responds to fields as a receiver. A discussion of the problem follows.

2.4.3 Mutual Impedance Between Two Arbitrary Antennas

In the following discussion we assume that the radiation is in the form of plane waves. This in effect means that the absolute value of the field does not vary over the length of the antenna for distances at which we are interested.

We know that a current in one element sets up a voltage in another. These may be coupled by radiation, in which case the radiation field from one antenna carrying current I_1 generates a voltage in the other and we may say that the impressed field on an antenna generates a voltage at its terminals. Since the antenna is a linear circuit element, we can say that the voltage at its terminals is proportional to the field intensity acting upon it. If this field varies along the antenna, it will be necessary to pick some reference point in space and say that

$$V = lE, \tag{35}$$

where E is the value of the field at this reference point and l is a constant of proportionality having dimensions of length, usually called the effective length. The term V is the open-circuit voltage at the antenna terminals. It is customary to select the feed point of the antenna as the reference point. If this is done, E will then represent the field intensity at this point in space if the antenna is assumed to be absent while the field intensity is determined.

Now consider two arbitrary antennas, No. 1 and No. 3, like those treated in Section 2.4.2, separated by distance r with currents I_1 and I_3 at the feed points. Assume that I_1 gives rise to a voltage V_3 at the terminals of No. 3 when I_3 is zero, and assume that I_3 gives rise to a voltage V_1 at the terminals of No. 1 when $I_1 = 0$. By means of equations (35) and (34) we can write

$$\begin{aligned} V_3 &= l_3 \frac{I_1}{r}\sqrt{\frac{Z_0 R_{s1} G_1}{4\pi}} f_1(\theta_{13},\phi_{13})\,(\cos\tau) j e^{j(-2\pi r/\lambda)}, \\ V_1 &= l_1 \frac{I_3}{r}\sqrt{\frac{Z_0 R_{s3} G_3}{4\pi}} f_3(\theta_{31},\phi_{31})\,(\cos\tau) j e^{j(-2\pi r/\lambda)}. \end{aligned} \tag{36}$$

Here we introduce the angle τ to take account of any skew relation between the two antennas.

[redacted]

Here $f_1(\theta_{13},\phi_{13})$ denotes the value of $f(\theta,\phi)$ for antenna No. 1 in the direction joining the fuze and target antennas No. 1 and No. 3 respectively, and $f_3(\theta_{31},\phi_{31})$ has an analogous meaning.

At this point we shall call upon the Rayleigh-Carson reciprocity theorem. The statement of this theorem as given by Carson is as follows:[95]

"Let an emf E_1', inserted in any branch, designated as No. 1, of a transducer, produce a current I_2' in any other branch, No. 2; correspondingly, let an emf E_2'' inserted in branch No. 2 produce a current I_1'' in branch No. 1; then $I_1''E_1' = I_2'E_2''$."

A transducer is defined as "a complete transmission system which may or may not include a radio link, which has accessible branches, either of which may act as the transmitting branch while the other acts as the receiving branch."

The theorem of reciprocity applied here means that

$$\frac{V_3}{I_1} = \frac{V_1}{I_3} = Z_{13} = \frac{l_3}{r}\sqrt{\frac{Z_0R_{s1}G_1}{4\pi}}\, f_1(\theta_{13},\phi_{13})\ (\cos\tau) je^{j(-2\pi r/\lambda)}. \tag{37}$$

Equations (36) and (37) give

$$l_3\sqrt{\frac{Z_0R_{s1}G_1}{4\pi}}\, f_1(\theta_{13},\phi_{13}) = l_1\sqrt{\frac{Z_0R_{s3}G_3}{4\pi}}\, f_3(\theta_{31},\phi_{31}), \tag{38}$$

or

$$\frac{l_3}{\sqrt{\frac{Z_0R_{s3}G_3}{4\pi}}\, f_3(\theta_{31},\phi_{31})} = \frac{l_1}{\sqrt{\frac{Z_0R_{s1}G_1}{4\pi}}\, f_1(\theta_{13},\phi_{13})}. \tag{39}$$

Thus for any antenna we may write

$$\frac{l}{\sqrt{\frac{Z_0R_sG}{4\pi}}\, f(\theta,\phi)} = C \tag{40}$$

where C is a constant not involving any of the variables in equation (39). Finally

$$l = C\sqrt{\frac{Z_0R_sG}{4\pi}}\, f(\theta,\phi), \tag{41}$$

showing that as a receiver the antenna behaves the same as a transmitter in its dependence on Z_0 R_s, G, and $f(\theta,\phi)$.

The mutual impedance between two arbitrary antennas can now be expressed. Antenna No. 1 impresses a field on antenna No. 3 as given by equation (34); antenna No. 3 receives it with an effective length l_3 given by equation (41).

$$Z_{13} = \frac{V_3}{I_1} = \frac{l_3E_1}{I_1} = \frac{CZ_0}{4\pi r}\sqrt{R_{s1}R_{s3}G_1G_3}\cdot f_1(\theta_{13},\phi_{13})\, f_3(\theta_{31},\phi_{31})\ (\cos\tau) je^{j(-2\pi r/\lambda)}. \tag{42}$$

If we can evaluate the constant C for any two antennas, we have it for all antennas. In Section 2.14 it is shown that C has the value $(2\lambda/Z_0)$. Inserting this into equation (42) gives

$$Z_{13} = \frac{\lambda}{2\pi r}\sqrt{R_{s1}R_{s3}G_1G_3}\, f_1(\theta_{13},\phi_{13})\cdot f_3(\theta_{31},\phi_{31})\ (\cos\tau) je^{j(-2\pi r/\lambda)}. \tag{43}$$

Equation (43) represents the mutual impedance between two arbitrary antennas separated far enough so that the radiation field ($1/r$ term) is the only one of importance.

We have seen in Section 2.3 that the antenna impedance of the fuze in the presence of reflecting targets can be represented as the sum of its self-impedance in free space plus terms involving mutual impedances Z_{ij} and the self-impedance of the reflectors. Equation (43) gives the analytic form of the mutual impedances Z_{ij}, if 1 and 3 be replaced by i and j, respectively.

We are now in position to apply this general formula to special cases representing a fuze approaching ground (interacting with its image) or a fuze approaching an airborne target well away from the ground.

2.5 ANALYTICAL FORM OF REFLECTED IMPEDANCE[b]

The analytic expression equation (43), derived in the preceding section, will be applied to three special cases and appropriate working formulas discussed. The general properties of the reflected impedance common to all three cases will then be discussed.

[b] Bibliographical references pertinent to this section are 1, 13, 16, 17, 22, 27, 51, 53, 93.

The general equations for the total antenna impedance of the fuze discussed in Section 2.3.1 were applied to three special cases with the following results:

Case I. Ground Approach.

$$Z_1 = Z_{11} - Z_{12}. \qquad (24)$$

Case II. Airborne Target Far From Ground.

$$Z_1 = Z_{11} - \frac{Z_{13}^2}{Z_{33}}. \qquad (25)$$

Case III. Ground Interference Case.

$$Z_1 = Z_{11} - Z_{12} - \frac{(Z_{13} - Z_{14})^2}{Z_{33} - Z_{34}}. \qquad (23)$$

Each of these equations is of the form

$$Z_1 = Z_{11} - Z_r, \qquad (44)$$

where Z_r represents the reflected impedance. The vector interpretation of this equation has already been given in Figure 1.

2.5.1 Ground-Approach Equation

A fuze approaching ground, in the absence of other reflectors, is interacting with its image and $Z_r = Z_{12}$. Furthermore, since antenna No. 2 is the image of antenna No. 1, we see that

$$\begin{aligned} R_{s1} &= R_{s2}, \\ G_1 &= G_2, \\ f_1(\theta_{12},\phi_{12}) &= f_2(\theta_{21},\phi_{21}), \\ \tau &= 0, \\ r &= 2h \ (h = \text{height above ground}). \end{aligned}$$

Introducing these relations in equation (43), we have

$$Z_r = Z_{12} = \frac{\lambda}{4\pi h} GR_s f_1^2(\theta_{12},\phi_{12}) j e^{(-j4\pi h/\lambda)}. \qquad (45)$$

Equation (45) gives the detailed form of Z_r for approach to a perfectly reflecting ground of large extent. As in equation (29) and subsequent equations a possible additive phase shift is ignored. From the results obtained in the case of the perfect reflector, we may extrapolate to actual grounds (plane reflectors) by the use of a reflection coefficient n. For purposes of these applications, the effective reflection coefficient n for a given surface is defined in such a way that the signal magnitude received by a fuze circuit, because of the presence of the surface, is n times the signal that would be received from a perfect reflector in the same position as the actual reflector.

This definition was set up to avoid possible errors in using the reflection coefficients derived for plane waves on the classical theory. (The equiphase surfaces of radiation from the fuze antennas have appreciable curvature at the usual distance of interest in fuze applications.) As a matter of fact, however, it has been found that the values of n found according to the above definition agree well with the published values of n based on the plane wave theory and, to the accuracy needed for fuze calculations, are independent of the height above the ground. Additional comments regarding n are to be found in Sections 2.9 and 2.14.

The reflection coefficient n has been measured by moving a fuze over a perfect reflector then over ground and comparing results (see Section 2.9).

When the reflection coefficient is included, we have

$$Z_r = \frac{n\lambda}{4\pi h} GR_s f_1^2(\theta_{12},\phi_{12}) j e^{(-j4\pi h/\lambda)}. \qquad (45a)$$

2.5.2 Airborne Target Equation

For target and fuze a long way from ground

$$Z_r = \frac{Z_{13}^2}{Z_{33}}.$$

With the aid of equation (43) we get

$$Z_r = -\left(\frac{\lambda}{2\pi r}\right)^2 \cdot \frac{R_{s1}R_{s3}G_1G_3 f_1^2(\theta_{13},\phi_{13}) f_3^2(\theta_{31},\phi_{31})\cos^2\tau}{Z_{33}} e^{-j4\pi r/\lambda}. \qquad (46)$$

Equation (46) is limited in its application to cases where the target can be considered as a single antenna with a single feed point. Thus it represents the case for a dipole reflector or a strip of "window." If the target can be represented as an array of simple antennas, then Z_r would involve mutual interaction with the whole family, including terms arising from the mutual interactions between members of the array.

If the target is not made up of linear anten-

[redacted]

nas but is a geometric shape capable of excitation in a complex manner, equation (46) cannot be used as it stands, since it is obvious that we cannot cut a complicated target arbitrarily and reproduce its complicated current distribution by feeding it at one point.

If we knew the current distribution on the target arising in response to the radiation from the fuze, we might proceed as follows: (1) find the number and location of the feed points necessary to reproduce this distribution, (2) determine $f(\theta,\phi)$ for the target when excited by each feed alone, (3) treat each feed with its $f(\theta,\phi)$ as a single antenna, (4) measure the mutual impedance between feed points, and (5) proceed with the general equations (21). For any ordinary target such a process is impossibly complicated, and we resort to more tractable methods.

Again we assume the fuze and the target to be far enough apart so that we can consider the fuze radiation to consist of plane waves at the target. We then determine the reflecting power A of the target as follows: (1) We irradiate the target with plane waves with a field intensity E_i, and (2) we measure the field E_r reflected back along the direction of the incident radiation. If this field E_r is measured at distance r from the target, A is defined by

$$E_r = \frac{E_i A}{r}. \tag{47}$$

The $(1/r)$ dependence of E_r is consistent with our initial assumptions concerning the plane waves from the fuze. Note that A has the dimensions of a length.

For a single linear antenna, it follows from the definition of A that A for such an antenna is given by

$$A = \frac{\lambda}{2\pi}\frac{R_{s3}}{Z_{33}} G_3 f_3^2\ (\theta_{31},\phi_{31}) \cos \tau. \tag{48}$$

As an example, consider A for a resonant half-wave reflecting dipole oriented for maximum reflection. In this case $R_{s3} = Z_{33}$; $G_3 = 1.64$, $f_3^2 = 1$ $\cos \tau = 1$, and $A_3 = 0.26$. Typical values of A for other simple reflectors are given in a paper by Mott.[93] In particular,

A (sphere) $= \frac{1}{2}a$, where a is the radius of the sphere;
A (flat sheet) $= \frac{L^2}{\lambda}$, where L^2 is the area of the sheet. (49)

We now express Z_r in terms of A as defined above with the aid of equation (48) and get,

$$Z_r = A\,\frac{\lambda}{2\pi r^2} R_{s1} G_1 f_1^2\ (\theta_{13},\phi_{13})\ (\cos\tau) e^{-j4\pi r/\lambda}. \tag{50}$$

For each antenna, τ is the angle between the plane of polarization of the incident radiation and the plane formed by r and the axis of the antenna.

If the antenna is a complicated structure, the meaning of A in equation (50) will require modification to include effects of the twisting of polarization of the incident radiation.

In the case of an actual aircraft target it would be necessary to know A at all angles, since the fuze sees a continually varying aspect as it approaches the target. Thus the calculation of Z_r by the use of equation (50) would require analytic expression of A as a function of direction toward the fuze.

The necessary information can be achieved in a more expeditious manner. An actual fuze is set up and the target moved past it slowly while the signal in the fuze is recorded. The recorded wave can be reproduced and used directly for testing fuze circuits. Such experiments are described in detail in Section 2.11.

To relate these measurements with our calculations the strength of the reflection was compared with the reflection from a resonant half-wave dipole, which can be computed directly from equation (46), giving

$$Z_r = 0.042\left(\frac{\lambda}{r}\right)^2 R_{s1} G_1 f_1^2\ (\theta_{13},\phi_{13}) e^{-j4\pi r/\lambda}, \tag{51}$$

for the dipole orientation which gives maximum reflection.

In general we find that the maximum reflection from the aircraft as it passes the fuze is N times the reflection from a dipole given by equation (51). It has the same dependence upon distance as a dipole for approaches that are not too close. The term N will not be a constant for a given target but will depend on λ.

From Mott's paper[93] we find that A for a flat sheet of area L^2 is L^2/λ, and A for a dipole is 0.26λ. Thus, a sheet of area L^2 is the equivalent of N dipoles, where

$$N = \frac{3.88L^2}{\lambda^2}.$$

[redacted]

With the aid of equation (51) this shows that Z_r is independent of λ for the case of a flat sheet.

2.5.3 Ground Interference

The general equation covering this case for a fuze and one target is given by equation (23):

$$Z_1 = Z_{11} - Z_{12} - \frac{(Z_{13} - Z_{14})^2}{Z_{33} - Z_{34}}. \qquad (23)$$

The detailed treatment of this case for a complicated target is beyond the scope of this report. However, certain general properties can be observed.

The symbol Z_r consists of two terms, the first representing the reflection from the ground and the second the reflection from the target, including the effect of the images. Now, in general, Z_{34} is small compared with Z_{33}; it will be 10 per cent or less for a dipole if the separation is 4 λ or more. Thus we may write Z_r as

$$Z_r = Z_{12} + \frac{(Z_{13} - Z_{14})^2}{Z_{33}},$$

with reasonable accuracy in so far as absolute magnitudes are concerned.

When the distance between antennas No. 1 and No. 3 is large compared to the distance between No. 1 and No. 2, $|Z_{13}|$ is nearly equal to $|Z_{14}|$ and the effect of the target is complicated by phase relations between Z_{13} and Z_{14}, giving rise to interference in the reflection which may be quite pronounced. However, when the fuze gets close to the target, or when the distance from fuze to target is much less than the distance between target and ground, Z_{14} and Z_{12} are small, and the signal is approximately equal to the free-space signal.

The situation is further complicated by the directional properties of target and fuze. In each impedance Z_{ij}, $f(\theta,\phi)$ must be evaluated in the direction (θ_{ij},ϕ_{ij}) from each antenna.

Any further discussion must be limited to special cases. One particular example is of interest. Neglecting directional factors, we compare the strength of the reflection from ground with the reflection from a resonant half-wave dipole oriented for maximum reflection to the fuze. We wish to determine at what distance r from a dipole the reflection is the same as from the ground at distance h.

From equations (51) and (45) $|Z_{12}| = |Z_{13}|$ when

$$0.042\left(\frac{\lambda}{r}\right)^2 f_1^2\,(\theta_{13},\phi_{13}) = \frac{\lambda}{4\pi h} f_1^2\,(\theta_{12},\phi_{12}).$$

Now if the radiation pattern of the fuze be such that

$$f_1^2\,(\theta_{13},\phi_{13}) = f_1^2\,(\theta_{12},\phi_{12}),$$

then the signals are equal when $r = \sqrt{0.52\lambda h}$. If λ is about 10 ft and h is 10,000 ft, then $r =$ 230 ft.

In the early days of fuze design this limitation caused some needless concern. In the first place the reflection from an airplane is of the order of 10 times that from a dipole. In the second place the radius of action of practical fuzes described in this volume is about 75 ft. In the third place the orientation with respect to the ground and the relative motions involved make the ground signal less important.

Only in special cases where the fuze is used against airborne targets near the ground does the ground reflection become a limitation on fuze operation.

2.5.4 Special Considerations of Transverse Antenna Fuze

In the preceding discussion it has been assumed that the fuze can be represented by a single antenna. This applies for fuzes using the missile as the antenna. In the cases of fuzes with transverse dipoles as antennas (T-51 and T-82), the expected variations of antenna impedance are complicated by the presence of the body of the missile near the fuze antenna. If the transmitter and receiver circuits are not electrically and mechanically balanced with respect to the missile, longitudinal currents are excited in it and these radiate energy. As a result there is in effect an additional antenna in the system, and its contribution to the performance of the fuze must be considered. Furthermore, even if perfect balance is obtained, the missile serves as a director or reflector behind the fuze to alter

its sensitivity pattern (see patterns in Section 2.8). We are not here concerned with this latter effect. We are concerned with the results of incidental unbalance that arises in the manufacture of fuzes.

To study them we idealize the system as two thin antennas arranged at right angles and concern ourselves with the reflected impedance Z_r when this system approaches the ground. To the extent that we can represent the system by two thin antennas the general arguments of Section 2.3 can be applied.

The arrangement to be considered is shown in Figure 7.

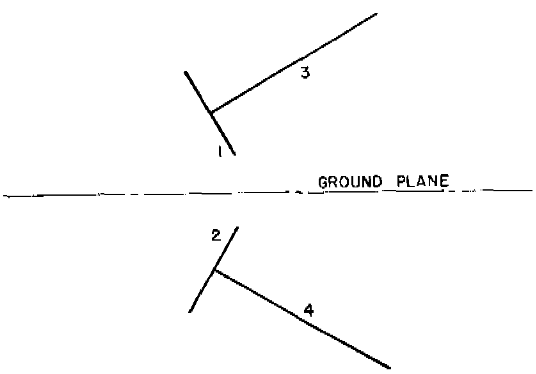


FIGURE 7. Representation of transverse dipole and projectile, with their images.

Antenna No. 1 is the fuze antenna. This case was treated in Section 2.3 for another purpose and led to equation (23), which is

$$Z_1 = Z_{11} - Z_{12} - \frac{(Z_{13} - Z_{14})^2}{Z_{33} - Z_{34}}. \tag{52}$$

To interpret this equation we expand and get

$$Z_1 = Z_{11} - Z_{12} - \frac{Z_{13}^2}{Z_{33} - Z_{34}} + 2\frac{Z_{13}Z_{14}}{Z_{33} - Z_{34}} - \frac{Z_{14}^2}{Z_{33} - Z_{34}}. \tag{53}$$

The first two terms of equation (53) represent the interaction of the T-51 or T-82 fuze with its image in the absence of any vehicle. Z_{11} represents the free-space impedance and Z_{12} the reflected signal. This has been generally interpreted as the actual working signal in the T-51 fuze when used. If the balance is perfect, $Z_{13} = 0$ and equation (53) reduces to

$$Z_1 = Z_{11} - Z_{12} - \frac{Z_{14}^2}{Z_{33} - Z_{34}}, \tag{54}$$

which shows that even though the projectile is not excited directly by the fuze antenna it nevertheless contributes to Z_r. In general Z_{34} is small compared to Z_{33} and serves to modulate the second-order reflection terms. We will neglect it in comparison with Z_{33} in the remainder of the discussion. Also we may use Z_{33} and Z_{44} interchangeably, since they are images of each other. The term (Z_{14}^2/Z_{44}) represents the reflection from the image of the projectile as a target for the fuze antenna.

To discuss the problem further we need a coordinate system. We choose the z direction as the axis of the missile with x and y axes perpendicular to it, the x axis being the axis of the transverse dipole. We also choose α as a polar angle. It is the angle between z and the normal to the ground, that is, the striking angle of the projectile referred to the vertical. The term δ is an azimuth angle measuring the angle between the x axis and the plane including the axis of the projectile and the normal to the ground (plane of incidence). To estimate the order of magnitude of this effect we shall make the further assumption that antenna No. 3, representing the projectile, is a resonant half-wave antenna. We shall also consider the radiation pattern of such an antenna to be $f(\theta) = \sin\theta$, when θ has the meaning previously assigned; this is a good enough approximation to the true pattern for this argument.

The field components from the x-axis dipole will be

$$\begin{aligned} E_r &= 0, \\ E_\alpha &= k_1 \cos\alpha \cos\delta, \\ E_\delta &= k_1 \sin\delta, \end{aligned} \tag{55}$$

where

$$k_1 = \frac{I_1}{r}\sqrt{\frac{R_{s1}G_1Z_0}{4\pi}}\, je^{-j2\pi r/\lambda}. \tag{56}$$

The component E_α will be in the vertical plane containing antenna No. 4 and will give rise to a voltage in it. The term E_δ will always be perpendicular to the plane and will produce no voltage in antenna No. 4. Thus Z_{14} will be

$$Z_{14} = \frac{E_\alpha l_4}{I_1},$$

$$Z_{14} = \frac{k_1}{I_1} l_4 \cos\alpha\cos\delta, \tag{57}$$

[redacted]

or

$$|Z_{14}| = \frac{2\lambda}{r}\sqrt{\frac{R_{s1}G_1}{4}}\sqrt{\frac{R_{s4}G_4}{4}}\cos\alpha\cos\delta\sin\alpha. \quad (58)$$

We then find

$$\left|\frac{Z_{14}^2}{Z_{44}}\right| = \frac{4\lambda^2}{r^2}\frac{R_{s1}G_1G_4}{(4\pi)^2}\cos^2\alpha\cos^2\delta\sin^2\alpha, \quad (59)$$

when we assume the projectile is resonant, so that $R_{s4} = Z_{44}$. This will give rise to a change $|(Z_r)_4|$ in antenna impedance in antenna No. 1 given by

$$|(Z_r)_4| = \left|\frac{Z_{14}^2}{Z_{44}}\right| = \frac{\lambda^2}{4\pi^2r^2}R_{s1}G_1G_4\cos^2\alpha\cos^2\delta\sin^2\alpha. \quad (60)$$

We compare this with the so-called normal impedance change

$$|Z_{12}| = \frac{\lambda}{2\pi r}R_{s1}G_1(1-\sin^2\alpha\cos^2\delta). \quad (61)$$

The worst case we will be interested in will be $\delta = 0$, $\alpha = 45$ degrees, and

$$|Z_{12}| = \frac{\lambda}{2\pi r}R_{s1}G_1\tfrac{1}{2}, \quad (62)$$

$$|(Z_r)_4| = \frac{\lambda^2}{16\pi^2r^2}R_{s1}G_1G_4. \quad (63)$$

The signals arising from Z_{12} and $(Z_r)_4$ will have an unknown phase relation depending upon striking angle and the size of the projectile. We consider the worst cases where they may be in or out of phase. The interference will change the response by the ratio

$$\frac{(\lambda/4\pi r)\,G_1 \pm (\lambda^2/16\pi^2r^2)\,G_1G_4}{(\lambda/4\pi r)\,G_1} \approx 1 \pm \frac{0.13\lambda}{r}. \quad (64)$$

For heights of operation of $r = 10\lambda$ (that is, $h = 5\lambda$) the maximum change in reflected signal will be approximately ± 1.3 per cent. For other angles $\alpha < 45$ degrees, $\delta \neq 0$ degrees, the correction will be less, being 0 for $\delta = 90$ degrees and all values of α.

We thus conclude that the variations in height of burst from the source are small for a perfectly balanced transverse antenna.

A greater source of error is the unpredictable value of δ. For $\alpha = 45$ degrees the reflected signal changes from 1 to ½ as δ varies from 90 to 0 degrees.

We now turn our attention to the correction arising when the antenna is not perfectly balanced. In this case $Z_{13} \neq 0$. There will be two terms of interest.

$$A = \frac{Z_{13}^2}{Z_{33}}. \quad (65)$$

$$B = \frac{2Z_{13}Z_{14}}{Z_{33}}. \quad (66)$$

The term A is a fixed term independent of r or h and shows merely the amount of reflected impedance in antenna No. 1 by virtue of its excitation of antenna No. 3 by some unbalance. This term, being constant, will give rise to no signals. It is merely a measure of the coupling between antenna No. 1 and antenna No. 3.

The term B gives rise to an additional signal. As before we will consider only absolute values and disregard relative phases, since the absolute values will indicate the maximum value of the corrections that may arise.

To estimate the coupling we note that I_1Z_{11} represents the free-space voltage at antenna No. 1. If Z_{13} is small we can say also that I_1Z_{13} represents the voltage coupled into antenna No. 3. We define k by the relation

$$k = \left|\frac{I_1Z_{13}}{I_1Z_{11}}\right| = \left|\frac{Z_{13}}{Z_{11}}\right|.$$

Experiments have shown that k is of the order 0.01 for well-balanced fuzes and may be as large as 0.1 for very poor balance, so poor in fact that the arrangement would never be used. These values are based upon the center point of the parasitic antenna as the reference point.

Now $|Z_{11}|$ is about 300 ohms and $|Z_{33}| > 73$ ohms. Hence $|Z_{13}|$ is approximately 3 ohms and

$$\left|\frac{B}{Z_{12}}\right| \leqq \frac{2\times 3}{73}\left|\frac{Z_{14}}{Z_{12}}\right| = 8 \text{ per cent of } \left|\frac{Z_{14}}{Z_{12}}\right|.$$

For all angles of approach that are of interest $|Z_{14}| < |Z_{12}|$ so that the correction is less than 10 per cent. If the unbalance becomes large this correction becomes sizable and can lead to a considerable change in function height. In most cases the projectile is nonresonant and $|Z_{33}|$ is considerably greater than 73 ohms. Thus incidental unbalance is not so important when the projectile is nonresonant. When resonance is approached the response becomes critical to unbalance as has been experimentally observed.

[redacted]

2.5.5 General Properties of the Reflected Impedance

We are primarily interested in the two basic equations, the ground-approach equation and the airborne-target equation. We repeat them here for convenience.

$$Z_r = \frac{\lambda}{4\pi h} G_1 R_{s1} f^2(\theta_{12},\phi_{12}) j e^{-j4\pi h/\lambda} \quad \text{(ground approach)}, \quad (45)$$

and

$$Z_r = \frac{-A\lambda}{2\pi r^2} R_{s1} G_1 G_1^2 (\theta_{13},\phi_{13}) (\cos \tau) e^{-j4\pi r/\lambda} \quad \text{(airborne target)}, \quad (50)$$

or in alternative form for a linear antenna reflector

$$Z_r = -\left(\frac{\lambda}{2\pi r}\right)^2 \cdot \frac{R_{s1} R_{s3} G_1 G_3 f_1^2(\theta_{13},\phi_{13}) f_3^2(\theta_{31},\phi_{31}) (\cos^2 \tau) e^{-j4\pi r/\lambda}}{Z_{33}}. \quad (46)$$

It should be remembered that the phase factor should carry an undetermined constant phase shift, related to the antenna properties of target and fuze.

DOPPLER FREQUENCY

As seen in Section 2.2 the phase has a frequency $F = (2v/\lambda)$, if $|(dh/dt)|$ or $|(dr/dt)|$ be replaced by v. This is identically the doppler frequency.

DEPENDENCE UPON R_s

Let us write R_s for R_{s1}. We note that Z_r is proportional to R_s, as would be expected, since it is the power dissipated in R_s that accounts for the radiation fields which make the interaction possible.

It will be observed in a later section that the dimensionless quantity (Z_r/R_s) is most convenient for assessing fuze circuit response. It exhibits the effect of a reflector as a fractional change in antenna impedance which depends only upon the nature of the target and the directive properties of the fuze antenna (which are relatively independent of R_s).

It has been found experimentally that small changes in the antenna feed point can change R_s over a wide range with almost no effect on $f^2(\theta,\phi)$. Thus the radiation patterns become characteristic of a given vehicle, and R_s can be adjusted to match the transmitter properly with the assurance that R_s will have little effect on Z_r/R_s.

A particular example is most enlightening. For antennas whose length lies in the range $0 \geqslant \lambda/2$, G varies from 1.5 to 1.64, about a 10 per cent change. The term $f^2(\theta,\phi)$ in the worst direction only differs by 15 per cent in the two extreme cases. Thus the quantity Z_r/R_s is practically independent of antenna length in this range. On the other hand, R_s varies from 73 ohms for a half-wave antenna to zero [as $(L/\lambda)^2$] for short antennas, where L is the length of the short antenna. We can thus state generally that all fuzes, whose response to a fixed value of (Z_r/R_s) is the same, will have practically the same response to a given target no matter what the length of the fuze antenna is, provided it is considerably less than a half-wave long. The statement is also true for all loop antennas whose dimensions are small compared with λ.

For longer antennas $f^2(\theta,\phi)$ is sensitive to λ, and each must be considered as a special case.

DEPENDANCE ON DISTANCE

The magnitude of (Z_r/R_s) depends upon the distance through the dimensionless ratio r/λ or h/λ. This means that λ is a scale factor in determining fuze performance. Response to the presence of a target is determined by the number of wavelengths in the distance to the target; thus, for example, the signal received from ground reflection at a given height is greater for greater λ.

DEPENDENCE ON DIRECTION TO TARGET: DEFINITION OF DIRECTIVITY

The size of Z_r/R_s is proportional to $G_1 f_1^2(\theta_{13},\phi_{13})$. Now G_1 is a constant for a given fuze so that $f_1^2(\theta,\phi)$ tells how well a fuze "sees" targets in various directions. The term $f_1^2(\theta,\phi)$ is the power radiation pattern of the fuze antenna; it is called the directivity pattern in this report. A plot of $f^2(\theta,\phi)$ will show (other things being equal) the distance at which a fuze will function upon approach to a target.

Now it will be observed that

$$\frac{G_1 f_1^2(\theta_{13},\phi_{13})}{4\pi} = \frac{W_{13}}{W} = F(\theta_{13},\phi_{13}), \tag{67}$$

where W_{13} is the power radiated per unit solid angle in the direction (θ_{13},ϕ_{13}) and W is the total power radiated. Thus $F(\theta_{13},\phi_{13})$ represents the fraction of the total power radiated per unit solid angle in the direction (θ_{13},ϕ_{13}). Thus $f^2(\theta_{13},\phi_{13})$ is an indication of how efficiently the total radiated power is used.

Typical directivity patterns are described in Section 2.8.

Independence of Power Level

It is clear, as was anticipated in Section 2.2, that Z_r/R_s does not depend upon the power level at which the fuze radiates.

2.6 CIRCUIT RESPONSE TO ANTENNA IMPEDANCE MODULATION

2.6.1 Series and Parallel Expressions for (Z_r/R_s)

Differential Signals

The foregoing analysis has been based upon the concept of series antenna resistance and reactance. In actual cases, however, it is often more convenient to deal with the equivalent parallel quantities. We therefore proceed to derive expressions for the changes in parallel antenna resistance and reactance due to a reflector.

We deal with the two circuits in Figure 8. The terms ΔR_s and ΔX_s, or ΔX_p and ΔR_p, are the changes in antenna resistance and reactance resulting from the presence of a reflector; R_p and X_p, or R_s and X_s, are the free-space values.

It is easily shown that in the absence of the incremental quantities we have

$$R_p = \frac{R_s^2 + X_s^2}{R_s}, \tag{68}$$

$$X_p = \frac{R_s^2 + X_s^2}{X_s}. \tag{69}$$

For small increments of impedance we may consider the differentials of R_p and X_p as equivalent to their increments.

Then

$$dR_p = \frac{dR_s}{R_s^2}(R_s^2 - X_s^2) + \frac{dX_s}{R_s^2}(2S_sR_s), \tag{70}$$

and

$$dX_p = dR_s\frac{(2X_sR_s)}{X_s^2} + \frac{dX_s}{X_s^2}(X_s^2 - R_s^2). \tag{71}$$

By defining $Q = X_s/R_s$ and by appropriate manipulation we find

$$\frac{dR_p}{R_p} = \frac{dR_s}{R_s}\left(\frac{1-Q^2}{1+Q^2}\right) + \frac{dX_s}{R_s}\left(\frac{2Q}{1+Q^2}\right), \tag{72}$$

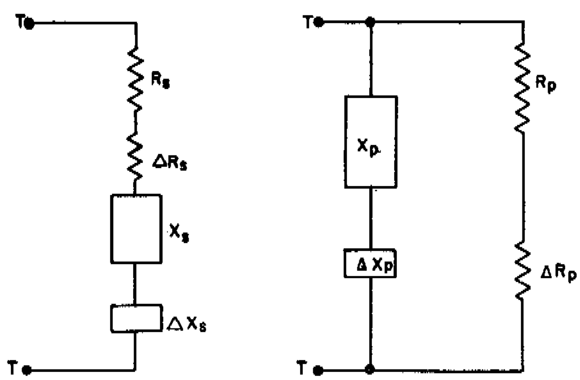
and

$$\frac{dX_p}{X_p} = \frac{1}{Q}\left[\frac{dR_s \cdot 2Q}{R_s(1+Q^2)} + \frac{dX_s(Q^2-1)}{R_s(Q^2+1)}\right]. \tag{73}$$

Now as we have seen, dR_s and dX_s are the components of a vector Z_r which may be written as

$$Z_r = |Z_r|e^{j\alpha},\ \alpha = \left(\frac{-4\pi x}{\lambda} + \delta\right), \tag{74}$$

where x represents the distance r or h from fuze to target. The term δ depends on the par-



SERIES CIRCUIT PARALLEL CIRCUIT

FIGURE 8. Series and parallel equivalent fuze circuits.

ticular case being discussed, but is unimportant for our present purposes. It will be found convenient to use the dimensionless ratio (Z_r/R_s) which we define as a new vector **M** and write

$$\mathbf{M} = M_0 e^{j\alpha},$$

where

$$M_0 = \frac{|Z_r|}{R_s}. \tag{75}$$

[redacted]

If we define an auxiliary angle β by the relations

$$\sin\beta = \frac{1 - Q^2}{1 + Q^2},$$

$$\cos\beta = \frac{2Q}{1 + Q^2}.$$

We can rewrite equations (72) and (73) as

$$\frac{dR_p}{R_p} = M_0 \sin(\alpha - \beta), \tag{76}$$

$$\frac{dX_p}{X_p} = \frac{M_0}{Q}\cos(\alpha - \beta). \tag{77}$$

For purposes of convenience, it may be desirable at times to work in terms of the admittance Y, which is defined through the relation

$$\begin{aligned} Y &= \frac{1}{R_s + jX_s}, \\ Y &= \frac{R_s}{R_s^2 + X_s^2} - j\frac{X_s}{R_s^2 + X_s^2}, \\ Y &= G - jB, \end{aligned} \tag{78}$$

where the conductance G and susceptance B are seen to be

$$\begin{aligned} G &= \frac{R_s}{R_s^2 + X_s^2}, \\ B &= \frac{X_s}{R_s^2 + X_s^2}. \end{aligned} \tag{79}$$

From equations (68) and (69) it is seen that

$$G = \frac{1}{R_p}$$

and

$$B = \frac{1}{X_p}. \tag{80}$$

Therefore

$$\frac{dG}{G} = -\frac{dR_p}{R_p}$$

and

$$\frac{dB}{B} = -\frac{dX_p}{X_p}. \tag{81}$$

FINITE SIGNALS

It will be observed later in the chapter that the actual working signals when the fuze is operating normally are so small that the differential representation given above is completely adequate. However, when tests are made on the fuze by measuring its response close to a large conductor, the impedance Z_r becomes a sizable fraction of R_s. We need expressions for the corrections that may be needed in interpreting such tests. By replacing R_s by $(R_s + \Delta R_s)$ and X_s by $(M_s + \Delta X_s)$ in equations (68) and (69), we get

$$\frac{\Delta R_p}{R_p} = \frac{1}{1 + M_0\cos\alpha}\left[M_0\sin(\alpha + \beta) + \frac{1}{1 + Q^2}M_0^2\right], \tag{82}$$

$$\frac{\Delta X_p}{X_p} = \frac{1}{1 + \frac{M_0}{Q}\sin\alpha}\left[\frac{1}{Q}M_0\cos(\alpha + \beta) + \frac{1}{1 + Q^2}M_0^2\right]. \tag{83}$$

It will be observed that these equations reduce to the differential forms when M_0 is small enough. For larger signals the equations indicate the presence of a "d-c shift" which is small when Q is large. They also show that equation (76) is in error by a fraction equal to M_0 even for very large Q. Thus in tests where M_0 is 10 per cent the field measurements are accurate to 10 per cent and can be corrected if desired. Some caution must be used in applying equations (82) and (83) to an actual case since induction fields will also contribute to Z_r at about the same separation that leads to large M_0.

However, in most fuze applications M_0 is about 0.5 per cent, and the differential forms have ample accuracy.

2.6.2 Specification of Fuze Circuit Parameters

It has been shown that both the resistive and reactive components of the antenna are altered by the presence of a reflector. To make a working fuze it will be necessary to devise a circuit which will respond in some manner to the change in antenna impedance. Such circuits are described in detail in Chapter 3.

For purposes of further analysis we assume that the voltage or current in some part of the fuze circuit changes in response to the antenna variations and that this change is used to actuate the fuze. We will call this particular fuze parameter V, representing a voltage, although it might as well represent a current. In order to continue the discussion of the antenna prob-

[redacted]

lem, we assume that the behavior of the circuit is known and that

$$V = f(\ln R_s, \ln X_s) = g(\ln R_p, \ln X_p), \tag{84}$$

where for purposes of convenience we express the functional relationship in terms of the natural logarithm of the impedance components. Thus

$$dV = \frac{\partial V}{\partial \ln R_p} d(\ln R_p) + \frac{\partial V}{\partial \ln X_p} d(\ln X_p),$$
$$dV = \frac{\partial V}{\partial \ln R_s} d(\ln R_s) + \frac{\partial V}{\partial \ln X_s} d(\ln X_s). \tag{85}$$

We define

$$S_p = \frac{\partial V}{\partial \ln R_p}; \quad S_s = \frac{\partial V}{\partial \ln R_s};$$
$$T_p = \frac{\partial V}{\partial \ln X_p}; \quad T_s = \frac{\partial V}{\partial \ln X_s}. \tag{86}$$

The quantities S_p, T_p or their corresponding transforms S_s, T_s describe the behavior of the fuze circuit when the antenna impedance varies. S_s and S_p are called the series and parallel resistance sensitivities respectively and T_s, T_p are called reactance sensitivities in a similar manner. All four quantities are functions of X_s, R_s or X_p, R_p which make up the free-space input impedance Z_0 of the antenna. In Chapter 3 the values of these quantities for typical circuits will be derived.

With the aid of the definitions of equation (86) we may write

$$dV = S_s \frac{dR_s}{R_s} + T_s \frac{dX_s}{X_s},$$
$$dV = S_p \frac{dR_p}{R_p} + T_p \frac{dX_p}{X_p}; \tag{87}$$

$$dV = M_0 \left(S_s \cos\alpha + \frac{T_s}{Q} \sin\alpha\right),$$
$$dV = M_0 \left[S_p \sin(\alpha+\beta) + \frac{T_p}{Q} \cos(\alpha+\beta)\right]. \tag{88}$$

If we make use of the complex notation and always consider dV to be the real part of a corresponding complex quantity, we may write

$$dV = MS = M_0 S_0 e^{j(\alpha - \eta)}, \tag{89}$$

where

$$S = \left(S_s - j\frac{T_s}{Q}\right).$$

$$S = \left(S_p \sin\beta - \frac{T_p}{Q}\cos\beta\right) - j\left(S_p\cos\beta - \frac{T_p}{Q}\sin\beta\right); \tag{90}$$

$$S_0 = \sqrt{S_s^2 + \left(\frac{T_s}{Q}\right)^2} = \sqrt{S_p^2 + \left(\frac{T_p}{Q}\right)^2} = |S|; \tag{91}$$

$$\tan\eta = \frac{T_s}{QS_s} = \frac{2QS_p - \dfrac{T_p}{Q}(1-Q^2)}{S_p(1-Q^2) + 2T_p}. \tag{92}$$

The appearance of the terms T_s/Q and T_p/Q in equations (91) suggests redefinitions of T_s and T_p to include Q. This can be done (see Chapter 3), but T_s and T_p so defined will then not have the logarithmic form commonly used for S_s and S_p. We keep the Q to maintain symmetry with the commonly accepted notation.

Since we are dealing with different mathematical representations of the same antenna the voltage change dV will be the same no matter which representation is used. This was implicit in equation (89).

The basic equation (89) represents in simple form the response of the fuze circuit to a moving target. While η is a fixed quantity for any given fuze, α $(= -4\pi x/\lambda + \delta)$ varies with fuze-target separation and therefore with time. The voltage change is seen to be proportional to M_0 and to S_0, the r-f sensitivity. If the fuze has reactance sensitivity as well as resistance sensitivity, both contribute to S_0 and give rise to a phase shift η in the voltage wave dV. By a proper selection of antenna coupling, it is often possible to operate near a resonance of the driving circuit, whereupon T_p approaches zero and there is little or no phase shift η.

Inasmuch as dV is proportional to M_0, a space plot of the variation of antenna impedance will likewise be a space plot of the variation of output voltage. This is a most important point to remember. For it means that the voltage out of the r-f system can be plotted point by point for a slow relative motion of fuze and target to give detailed information on the performance in rapid motion. All that need be changed is the time scale; the fuze antenna goes through its sequence of variations in whatever time is required for the fuze to move through the region of influence, and the wave form will be identical in every case. This as-

[redacted]

sumes, of course, that the circuit is capable of following the time variations, which experience has shown is no restriction.

The space variation of M which gives the voltage variation has been called the M wave and is so referred to in the discussion which follows. Extensive use is made of point-by-point plots of the M wave in testing fuzes.

We note that S may be measured as dictated by convenience in terms of either series or parallel components, and that the complex form of S is completely specified by either set of measurements, as shown by equations (89), (90), and (91). In many cases T_s/QS_s and T_p/QS_p are small compared with unity, so that

$$S_s = -S_p = \pm S_0 = \pm |S|.$$

In any case the basic equation (89) which represents the situation is

$$dV = MS = M_0 S_0 e^{j(\alpha - \eta)}.$$

We apply this to the two special cases in which we are interested.

For the ground-approach case we have, utilizing equation (45a),

$$M = \frac{n\lambda}{4\pi h} Gf^2(\theta,\phi)e^{j\alpha}. \tag{93}$$

For the airborne target we have from equation (50)

$$M = \frac{A\lambda}{2\pi r^2} Gf^2(\theta,\phi)\ (\cos \tau)e^{j\alpha}. \tag{94}$$

Subscripts previously used in connection with A, G, f, θ, and ϕ will no longer be carried except in cases where there may exist a possibility of misunderstanding.

2.7 ANTENNA IMPEDANCE[c]

The previous section has shown that a knowledge of the components of Z_{11}, the free-space antenna impedance, is essential if circuit response to the reflected impedance arising from reflection is to be predicted. This section is concerned with the values of antenna resistance and reactance observed in actual cases.

Specifically the resistance and reactance sensitivities of the fuze circuit are functions of (X_s,R_s) or (X_p,R_p) and must be evaluated at the particular operating point characteristic of the particular antenna used. Since the various missile-antenna combinations present widely different impedances, it becomes necessary to measure, or in some cases to calculate, the sensitivity parameters for a given circuit over a large range of load impedance, so that the antenna can be designed to have an operating point as near as possible to the optimum point for circuit response. It should be pointed out here that there are limitations to the antenna impedance that can be achieved within the limits set by the tactical situation and by specified military characteristics. Likewise the values of S can be changed by circuit design only, within certain limits set by present-day vacuum tubes. Thus antenna design must be coordinated with circuit design to give optimum performance within the limits of both. In addition it is necessary to set up dummy antennas for testing fuzes. A knowledge of actual antenna impedance is essential here also. In this section we are concerned with the antenna impedances that can be effectively achieved. Chapter 3 will give details about the circuit performance under the load and load variations presented by the antenna.

2.7.1 Specification of Antenna Terminals

In all the previous discussion the fuze antenna has been treated as a two-terminal box which sends out radiation. No detailed knowledge of the internal circuit was assumed. We imagine this antenna to be connected to a circuit whose sensitivity is specified. Now when the whole is connected together, a given reflector in space sets up a certain ΔV in the r-f circuit. Once the whole arrangement is connected, the antenna terminals lose their identity and their location becomes arbitrary. Thus if we open the arrangement at any two points (see Figure 9) and call everything on one side of the cut the fuze circuit and everything on the other side the antenna, the values of X_p, R_p and S_p and T_p must be so related that the value

[c] The following bibliographical references are pertinent to this section: 6, 8, 11, 28, 30-34, 37, 38, 49, 50, 52, 54-60, 62-67, 69.

of ΔV calculated by their use is independent of the particular pair of points selected as antenna terminals.

Thus in specifying fuze performance or antenna performance we are at liberty to select any two terminals within the network as antenna terminals. It has been customary in variable-time [VT] fuze work to consider all the circuit elements inside the fuze electronic as the fuze circuit, even if the assembly contained some antenna impedance matching network, and consider the points where the leads from this circuit are connected to the external radi-

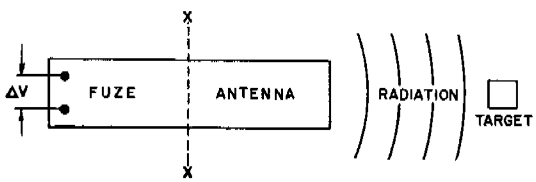


FIGURE 9. Arbitrary division into fuze circuit and antenna.

ating system as the antenna terminals. The discussion of the antenna problem has assumed that the only ohmic losses in the antenna are radiation losses. Experiments have shown this to be a valid assumption with the antenna terminals just specified. If some other pair of points is selected so that some energy-absorbing coupling elements are included in the network, due account must be taken of these losses.

2.7.2 Experimental Measurement of R_p

The parallel radiation resistance R_p is measured by a substitution method. A typical fuze circuit is used as an indicator. In the fuze circuit several quantities, such as diode voltage V_d or oscillator grid voltage E_g, oscillator plate current I_p, and carrier frequency f, are all functions of (X_p, R_p). The fuze is first placed on the projectile on a high stand and the free-space values V_d or E_g, I_p, and f noted. The fuze is then removed from the projectile and placed in a shield box. Reactance and resistance are added to the antenna terminals until the free-space values are duplicated. It is assumed that the shield box does not load the fuze at all, so that the amount of resistance across the terminals when the load is duplicated represents R_p.

In making this measurement the exciting cap or bars are often not removed. The resistors are merely substituted across the points that have been previously agreed upon as the antenna terminals. The shield adds reactance to the antenna so that direct measurements of X_p are not obtained this way.

To show that the shield does not introduce serious losses, the whole antenna is removed from the fuze and resistors substituted directly across the fuze terminals. The size of the arrangement is so small compared to λ that radiation is negligible and the substituted resistance represents R_p. By such tests it has been shown that shield losses are negligible, so that the more convenient shield box can be used where desired. In making this comparison test it is necessary to remove dielectric insulators so that losses in them do not confuse the measurements.

In the case of fuzes which use the projectile as the antenna, the radiation load is removed by putting a shield can over the nose fuze, as shown in Figure 10. Such an arrangement replaces radiating currents in the antenna by nonradiating currents inside the shield can and thus substitutes can losses for antenna losses in measuring R_p. If both are small compared with the true radiation losses, this substitution causes negligible error. The final proof that the errors are negligible is obtained by making a pole test (see Section 2.12) and comparing actual signal with calculated signal based upon

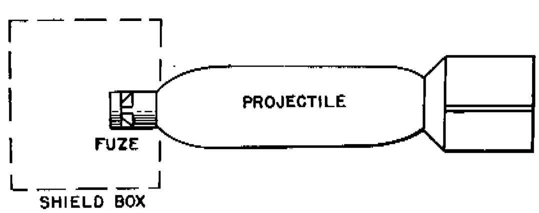


FIGURE 10. Method of removing radiation load without removing projectile.

the measured values of R_p and S_p. Within an experimental error of less than 10 per cent there is agreement.

It is interesting to note here that the absolute ohmic value of the substitution resistors used for the measurement of R_p need not be known.

[redacted]

Since M is proportional to dR_p/R_p, only ratios of resistances are needed, and any set of resistors whose r-f resistance is a constant fraction of the d-c resistance may be used. It has been found that International Resistance Company [IRC] type F-1 or F-½ resistors fulfill this requirement; in fact their r-f values are quite close to their d-c values. However, if it is of importance to know the power radiated, as is the case in jamming calculations, the true value of the r-f resistance must be known. It has been customary for all collaborating laboratories to use equivalent sets of r-f resistors supplied by a central laboratory.

2.7.3 Specification of X_p

The quantity T_p/QS_p appearing in equation (91) is in many cases so small that it can be neglected, as has already been mentioned. To see this, the value of T_p/QS_p at the operating point must be evaluated, a procedure which requires knowledge of X_p. The question immediately arises: Is the total apparent reactance across the antenna terminals the correct value of X_p, or should we use only the part that appears by virtue of radiation? The argument above about specification of antenna terminals implies that either arrangement should give the same answer. The r-f section of the fuze can be represented in block diagram as in Figure 9. The target in space gives rise to a certain ΔV out of the terminals to the audio-control circuit. We are at liberty to divide the whole arrangement at any convenient place by a line xx and call the left part the fuze and the right part the antenna. If the calculations are performed properly, the result must be the same no matter where xx is chosen. We choose to put the fixed part of the antenna reactance to the right of xx and call it a part of the antenna. Similarly, if there are dielectric losses in the antenna mounting, we can assume them to be represented as a resistance across the antenna terminals and put it to the left of xx as a part of the fuze circuit. This is the adopted convention. As a matter of fact we can, if we desire, divide the X_p any way we choose between fuze circuit and antenna.

To illustrate the point we show that the quantity T_p/Q is independent of how X_p is defined

$$T_p = X_p \frac{\partial V}{\partial X_p}, \qquad Q = \frac{R_p}{X_p}. \tag{95}$$

Suppose

$$X_p = \frac{1}{2\pi f C_p}.$$

This does not affect the generality of the result. Then

$$\frac{\partial V}{\partial X_p} = \frac{\partial V}{\partial C_p}\frac{dC_p}{dX_p}, \tag{96}$$

and

$$\frac{T_p}{Q} = \frac{X_p^2}{R_p}\frac{\partial V}{\partial X_p} = \frac{-1}{2\pi f R_p}\frac{\partial V}{\partial C_p}, \tag{97}$$

which shows that T_p/Q is independent of how C_p is defined.

2.7.4 Measurement of X_p

In the following discussion X_p is considered as the total reactance across the antenna terminals. The term X_p is measured by a direct substitution method. The fuze is mounted on a missile, and values of V_d or E_g, I_p, and f are recorded. The fuze is then removed from the vehicle and the circuit disconnected from the antenna at the previously selected terminals. Resistors and condensers are placed across the terminals until V_d, I_p, E_g, and f are duplicated, thus duplicating R_p and X_p. For all fuze designs now used X_p is capacitative. To a good approximation X_p is the capacity across the antenna terminals as measured by low-frequency methods. This is shown by the fact that X_p varies only slightly with projectile size.[31]

2.7.5 Effect of Feed Geometry upon R_p and X_p

Figure 11 shows the effect upon R_p of changing the size of the exciting ring on the T-50 type of fuze, with the spacing from ring to ground held constant at 1 in. Results are shown for several bombs, two carrier frequencies (White and Brown) for ring lengths ranging

from ¼ to 3 in. As expected, an increase in ring length decreases R_p.

The effect of ring length upon C_p is shown in Figures 12 and 13 for Brown and White fre-

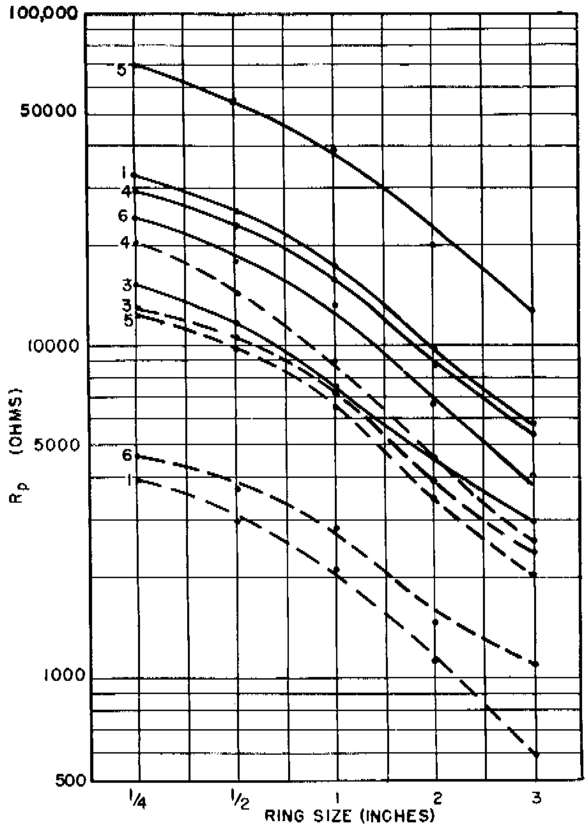


FIGURE 11. R_p as function of ring size; BRLG-type fuze; gap width, 1 in.; solid lines, Brown frequency; broken lines, White frequency; curves 1, M-30 100-lb bomb; curves 3, M-64 500-lb bomb; curves 4, M-65 1,000-lb bomb; curves 5, M-66 2,000-lb bomb; curves 6, M-81 260-lb bomb.

quencies respectively, with a constant gap size of 1 in. In Figures 12 and 13 the capacity is shown as 6.9 μμf for all the bombs, for a ring length of 1 in. This is not precisely correct, as capacities associated with the various projectiles vary somewhat; the curves are meant to indicate the variation of the capacity with ring size. The value 6.9 μμf is not far from correct, however; for all the bombs, the true range of values at the 1-in. point is about 6.9 ± 0.5 μμf. An increase in ring length increases C_p.

The effect of gap size upon R_p and C_p is shown in Figure 14. The size of the gap in the range shown (spacings from ½ to 1 in.) has virtually no effect upon R_p. The term C_p, of course, decreases as the spacing is increased. It thus becomes possible, within the limitations of space requirements, to vary the gap size to bring C_p to a favorable value without affecting R_p.

In the case of transverse center-fed dipoles (T-51, T-82) C_p is increased by increasing the size of the dipoles or by reducing their separation. The term R_p decreases when the size of the dipole is increased ($l << \lambda$). While it is an advantage to get lower R_p by using longer dipoles, air resistance and operational difficul-

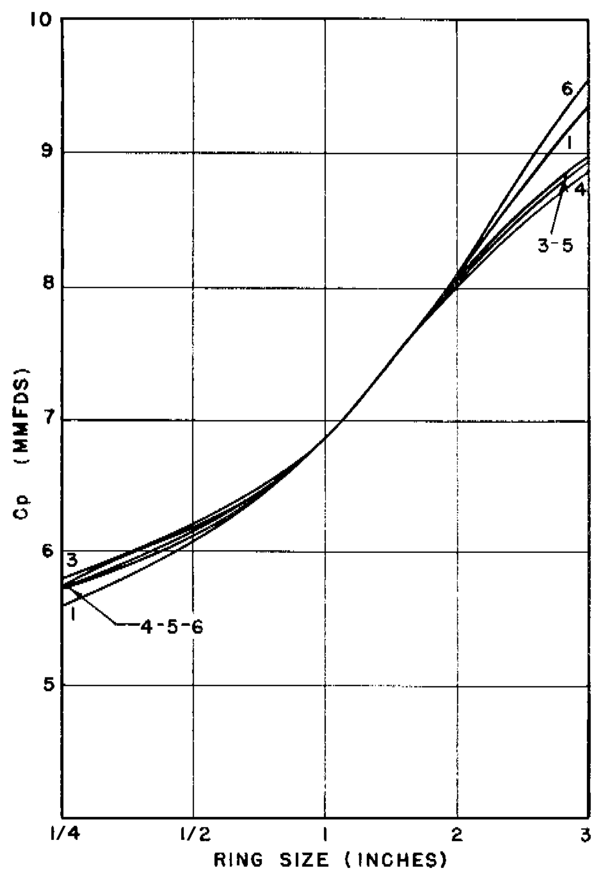


FIGURE 12. C_p as function of ring size; BRLG-type fuze; gap width, 1-in.; Brown frequency; curve 1, M-30 100-lb bomb; curve 3, M-64 500-lb bomb; curve 4, M-65 1,000-lb bomb; curve 5, M-66 2,000-lb bomb; curve 6, M-81 260-lb bomb.

ties increase with increasing length, and these considerations serve to limit the length of antenna which may be used. Electric efficiency must be subordinated in this design.

2.7.6 Typical Values of R_p and X_p

Figure 15 shows the value of R_p as a function of carrier frequency for several common bombs using a standard T-50 ring; the feed must be specified since R_p depends on it. The large range of values for all bombs at any one frequency illustrates clearly the difficulty of designing a single fuze which will work on all bombs. It was for this reason among others that the T-51 type transverse antenna fuze was designed. The T-51 with its independent antenna has radiation resistance relatively independent of projectile size.

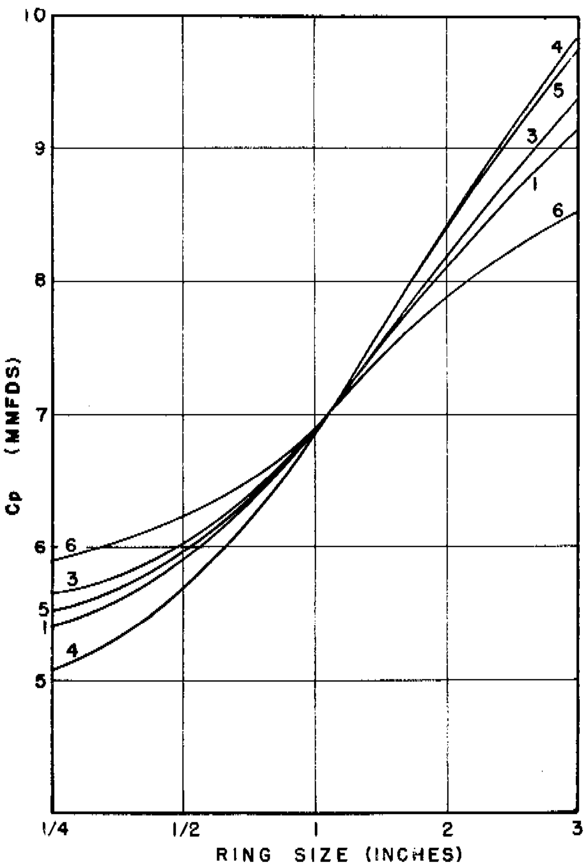


FIGURE 13. C_p as function of ring size; BRLG-type fuze; gap width, 1 in.; White frequency; curve 1, M-30 100-lb bomb; curve 3, M-64 500-lb bomb; curve 4, M-65 1,000-lb bomb; curve 5, M-66 2,000-lb bomb; curve 6, M-81 260-lb bomb.

The logarithmic spread in R_p among the vehicles tends to decrease as the frequency is lowered. The mean value of R_p increases. Until recently, as shown in the next chapter, it was

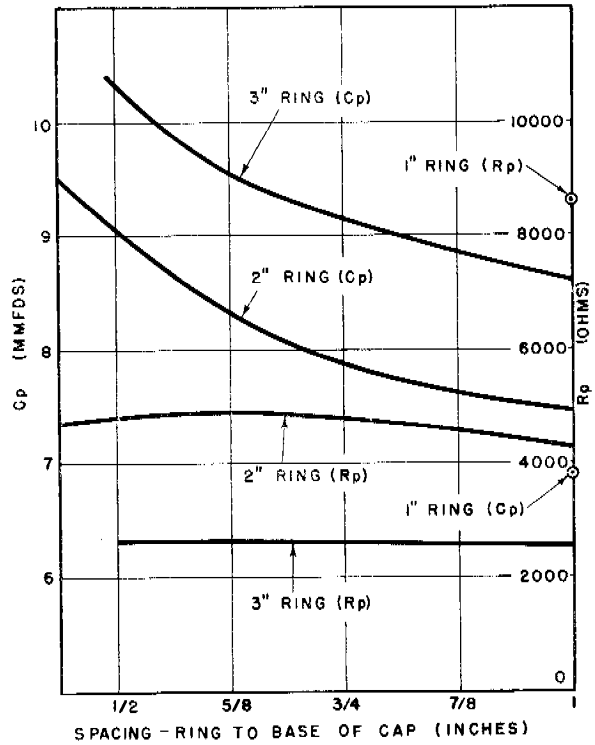


FIGURE 14. Effect of gap size upon R_p and C_p; BRLG-type fuze; M-65 1,000-lb bomb; White frequency.

not feasible to operate fuze circuits into a mean value of R_p as high as 40,000 ohms. The improved reaction grid detector [RGD] circuit

FIGURE 15. R_p as function of carrier frequency; T-50 ring; curve 1, M-30 100-lb bomb; curve 2, M-57 250-lb bomb; curve 3, M-64 500-lb bomb; curve 4, M-65 1,000-lb bomb; curve 5, M-66 2,000-lb bomb; curve 6, M-81 260-lb bomb.

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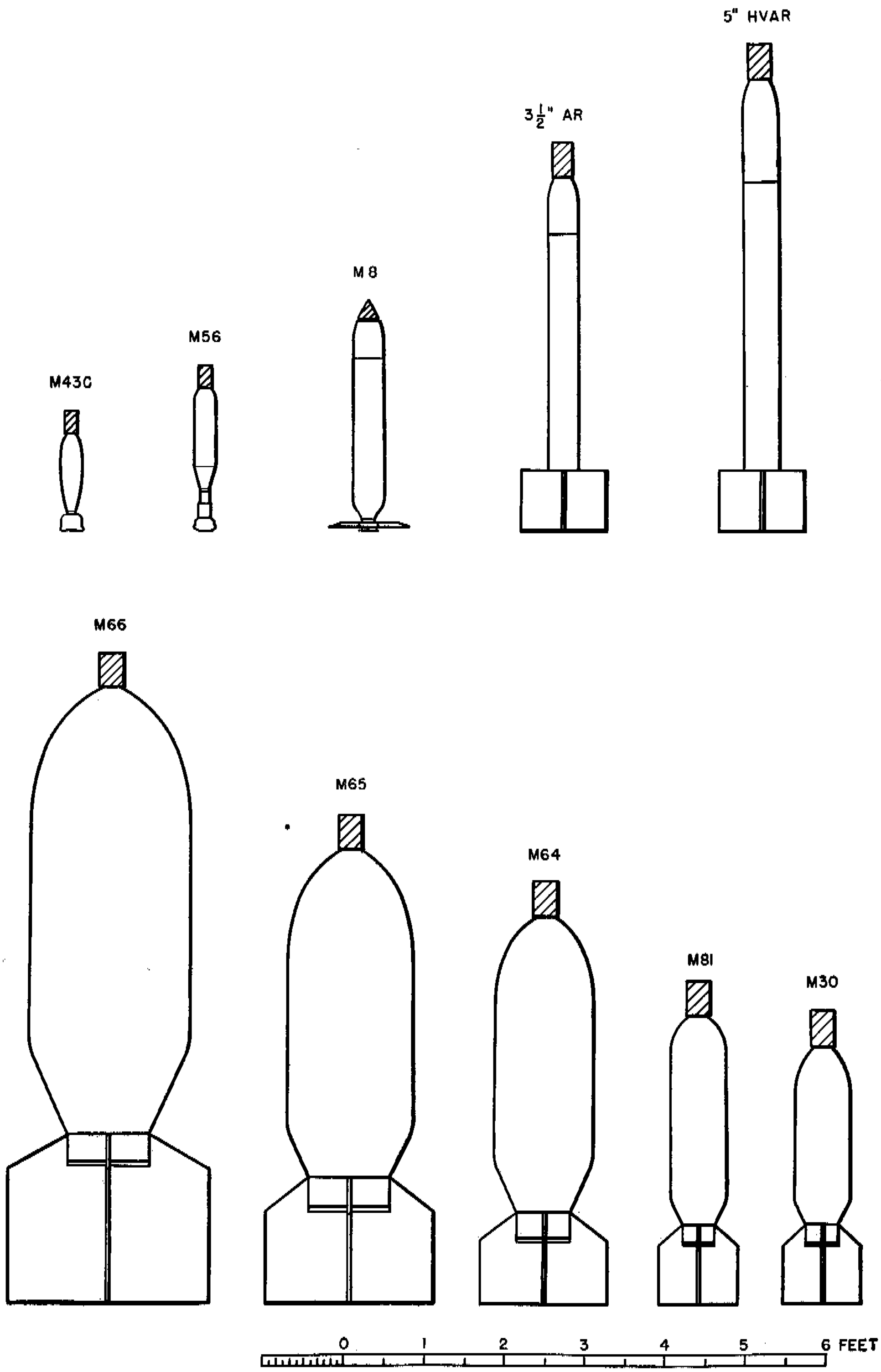

FIGURE 16. Scale outline drawings of a number of missiles for which VT fuzes were designed. Fuzes with longitudinal excitation were designed for all missiles shown. Transverse antenna fuzes were also designed for bombs. To show the relative size of fuze and missile, the outline of the fuze is shaded.

[redacted]

described in Section 3.1 makes it possible to use one frequency for a large number of projectiles by allowing operation at a high value of R_p.

Complete tables of R_p and X_p are not available for all projectiles. Table 1 gives the values at important frequencies for fuze projectile combinations of current interest. The range of missile sizes for which fuzes were designed is illustrated in Figure 16. Photographs of typical fuze and missile combinations are shown in Figure 7 of Chapter 1.

TABLE 1. Typical values of R_p and X_p for various fuze-projectile combinations.

Fuze type	Projectile	Carrier frequency	R_p (ohms, approx.)	X_p (ohms, approx.)
T-91	M-30 bomb (100-lb GP)	Brown	20,000	300
T-91	M-66 bomb (2,000-lb GP)	Brown	40,000	300
T-92	M-64 bomb (500-lb GP)	White	11,000	200
T-92	M-65 bomb (1,000-lb GP)	White	10,000	200
T-132	M-43 mortar with M-56 tail	White + 20	20,000	150
T-132	M-56 mortar	White + 20	6,000	150
T-171	M-43 mortar with M-56 tail	Brown	90,000	300
T-171	M-56 mortar	Brown	60,000	150
M-166	....	White + 35	150,000	600
T-2005	HVAR rocket	Brown	3,800	150
	AR 5-in. rocket	Brown	3,600	150
T-5, T-6	M-8,4½-in. rocket	White + 30	8,000	300

2.8 DIRECTIVITY PATTERNS[d]

We come now to a more detailed study of the properties of $f^2(\theta,\phi)$, the power radiation pattern or directivity pattern. The importance of $f^2(\theta,\phi)$ was indicated in Section 2.5 above, where it was shown that the reflected impedance Z_r, due to an object situated in a direction (θ_{13},ϕ_{13}) relative to the fuze, is proportional to $f_1^2(\theta_{13},\phi_{13})$. Furthermore, the gain G is a function of $f^2(\theta,\phi)$.

[d] Bibliographical references pertinent to this section are 6, 8, 36, 40, 47, 50, 52, 54-60, 62, 63, 64, 68.

2.8.1 Measurement of Directivity Patterns

EXPERIMENTAL SETUP

The simple convenient method which has been devised for the measurement of directivity patterns may be understood with the help of the photographs in Figures 17, 18, and 19. In Figure 17 the antenna, which consists in this case of the projectile plus the fuze in its nose, is mounted horizontally on a platform about 15 ft above the ground. The platform is free to rotate about a vertical axis (Figures 18 and 19). The receiver (Figure 17), consisting of a dipole antenna feeding a detector, is situated about 150 ft from the transmitter. Power is fed to the transmitting antenna by means of a carefully choked line coming from the power supply on the ground. The line is attached to the antenna at a voltage node. The whole setup is situated in an open field. The radiating antenna can be rotated through any angle and the receiver signal plotted as a function of this angle. The plate supply of the transmitting oscillator is based upon an a-c source of 60 c. Full-wave rectification with no filtering is used; there is thus a plate modulation frequency of 120 c which can be detected at the receiver.

In the type of fuze antenna shown in the photograph, the directivity pattern has cylindrical symmetry because of the symmetry of the projectile. In such a case the directivity has no dependence upon ϕ, and the pattern may be represented analytically as $f^2(\theta)$. The angle of rotation about a vertical axis is then equal to θ; when the nose points directly at the receiver $\theta = 0°$. The detector used is of the square law variety, so that the audio signal is directly proportional to the square of the field strength or to $f^2(\theta)$.

Where cylindrical symmetry is not present, the pattern must be taken in several planes to get a reasonably complete set of values for $f^2(\theta,\phi)$. Such asymmetry may occur when the antenna is separate from the bomb, as in the T-51 and T-82 type designs, the bomb acting as a parasitic reflector or director.

DETECTOR CIRCUIT

Some notes may be added concerning the de-

tector circuit, shown in Figure 20. The circuit and physical layout are symmetrical, with a view to obtaining balance with respect to ground. This has the effect of minimizing the effect of any vertically polarized components of the field caused by reflection from the ground, which otherwise could alter the apparent shape

FIGURE 17. Field setup for obtaining directivity patterns.

of the directivity pattern, especially affecting the symmetry of the patterns.

The r-f chokes are for the purpose of reducing interference from transmitters operating in or around the broadcast region. These chokes have a high impedance at the carrier frequencies used in fuze antennas but a low impedance at lower frequencies. The coupling condensers

FIGURE 18. Rotatable platform holding fuzed bomb for directivity pattern measurements.

in the grid circuits prevent the grids from being shorted by the chokes at direct current. The condenser from the plates to ground serves as an r-f by-pass; it has a high impedance to audio frequencies.

The audio output is fed to a Ballantine-type vacuum-tube voltmeter, preceded if necessary by an amplifier.

The output of the detector follows quite accurately a square law for outputs up to 100 mv.

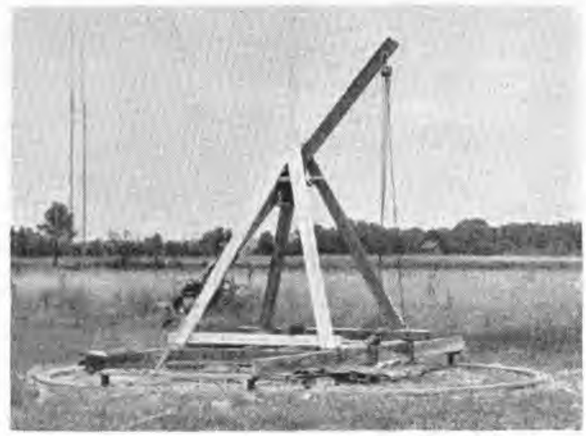

FIGURE 19. Platform of Figure 18 shown lowered to ground.

The output may be kept below this level by adjusting the power supply feeding the transmitting antenna.

REFLECTIONS FROM GROUND

The reflections from the ground contribute to the output of the detector and therefore may

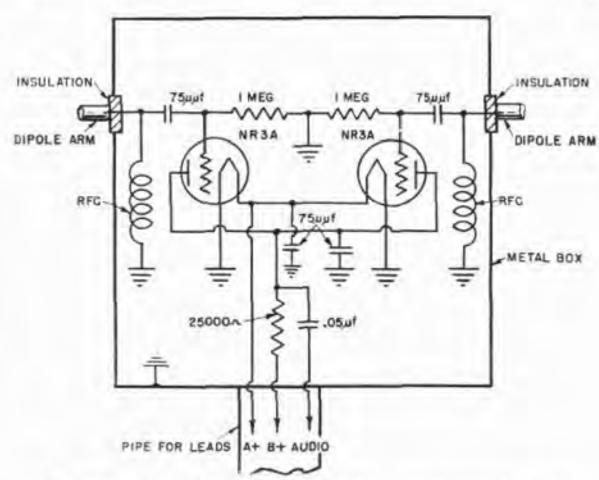

FIGURE 20. Detector circuit; components are enclosed in metal box mounted between arms of receiving dipole.

change the apparent directivity pattern. This matter has been studied and is presented in some detail as supplementary material in Sec-

tion 2.15, where it is shown that the ground reflection introduces negligible error for the simple radiation patterns now used.

By means of the equipment described above a large number of directivity patterns have been obtained. The patterns fall into two classes: (1) patterns for fuzes which use the projectile as the antenna (longitudinal excitation), and (2) patterns for fuzes which use a separate antenna such as a short transverse dipole or loop (transverse excitation). The patterns will be discussed according to this classification.

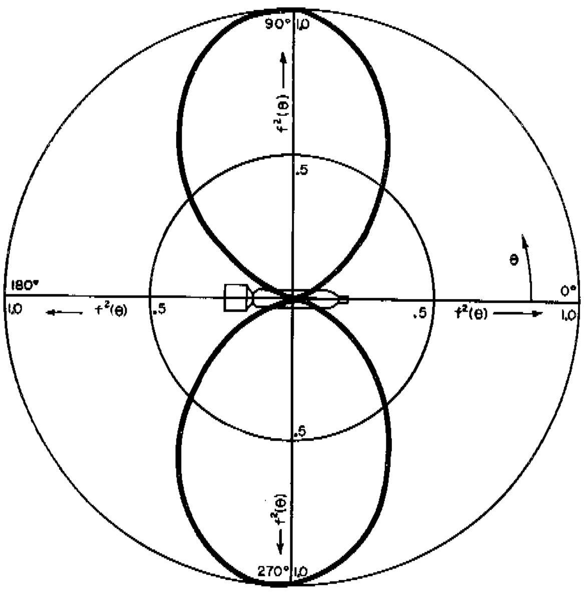

FIGURE 21. Directivity pattern for M-64 bomb at $B - 16$; longitudinal excitation; $G = 1.55$.

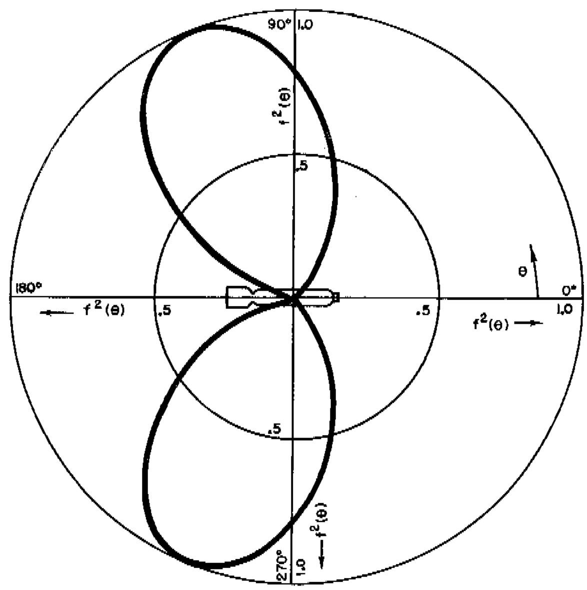

FIGURE 22. Directivity pattern for M-64 bomb at $B + 15$; longitudinal excitation; $G = 1.9$.

2.8.2 Longitudinal Excitation

TYPICAL PATTERNS

In longitudinal excitation the fuze proper is connected to the projectile at one end. The antenna, consisting of fuze and projectile, is split by an insulator near the end for the purpose of feeding energy to it. The exact position and size of the gap over the range used, while important in determining the antenna impedance, have little effect upon the pattern. Therefore it will not be necessary to specify the feed exactly in describing the patterns for longitudinal excitation.

A preliminary idea of the character of the patterns may be obtained from Figures 21, 22, and 23. These show the directivity patterns $f^2(\theta)$ plotted versus θ on polar coordinate paper; for these antennas, the directivity pattern is not a function of ϕ, cylindrical symmetry being present. Figures 21, 22, and 23, for a 500-lb GP bomb (M-64) at three carrier frequencies, demonstrate the effect of changing the frequency. As the carrier frequency is raised, which means the antenna becomes electrically longer, the pattern departs more and more from the simple sin θ pattern of an elementary dipole (shown in Figure 24). The minor lobes in the pattern for a carrier frequency of $W + 10$ (see Figure 23), will be noted. In these patterns, as in all the patterns obtained with longitudinal excitation, the radiation is more intense off the end of the antenna away from the feed point. This will be discussed below in greater detail. The values of G for each pattern are given in the captions to the figures. These values were obtained by graphical integration of the patterns. The effect of using one frequency for exciting various pro-

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jectiles is shown in Figure 25. Figure 25 represents a series of patterns at $W + 10$ for the M-30, M-81, M-64, M-65, and M-66 bombs. In this figure the patterns are plotted in rectangular coordinates.

Since tactical utility has required that the fuze be located in the nose of the projectile, we are interested in the values of $f^2(\theta,\phi)$ in front of the equatorial plane, i.e., for $\theta < 90$ degrees in the patterns of Figure 25. It is immediately may be expected from qualitative arguments. The antenna may be thought of, crudely, as a piece of transmission line with a generator at one end and an impedance at the other end. A wave starts out from the generator; some of it is absorbed in the impedance at the other end (radiation); the rest is reflected back. Since the amplitude of the wave traveling from the generator is greater than that of the return wave, the part of the radiation due to the for-

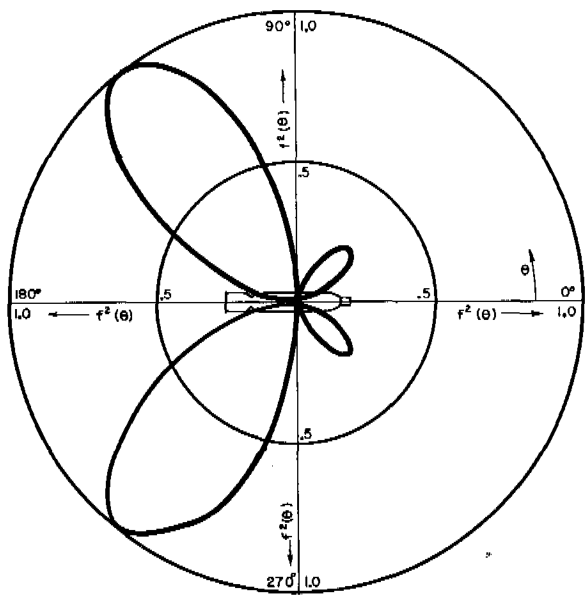

FIGURE 23. Directivity pattern for M-64 bomb at $W + 10$; longitudinal excitation; $G = 2.6$.

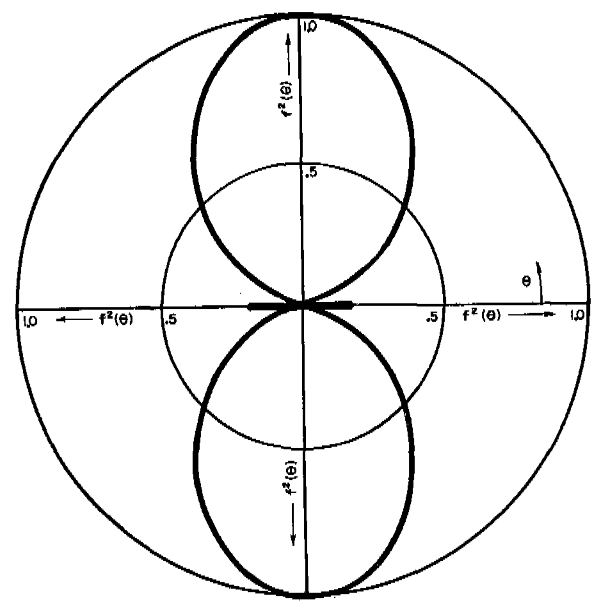

FIGURE 24. Directivity pattern for infinitesimal dipole; $f^2(\theta) = \sin^2(\theta)$; $G = 1.5$.

evident that there is a wide range in Z_r for targets in the range 10 to 90 degrees off the nose. This is a complicating factor which requires that more than one frequency be used in designing longitudinal antenna fuzes.

This is an unfortunate complication that could largely be avoided if the feedpoint could be located in the rear of the projectile.

General Features of Longitudinal Patterns

The directivity patterns obtained with longitudinal excitation have several general features worthy of note. Some of these have already been mentioned and will be treated here in somewhat more detail.

"Lean" of Patterns. The patterns "lean" away from the feedpoint. This characteristic ward wave, primarily forward radiation, is more dominant than the part due to the return wave.

For end-fed antennas, at a given frequency, the asymmetry is greater the greater the thickness of the antenna relative to its length. Center-fed antennas, even if of considerable thickness, have symmetrical patterns.

Patterns like those experimentally obtained may be computed by assuming an antenna current distribution with features as above described. That is, suppose we assume that the antenna current I is given by an expression of the form:

$$I = e^{j\omega t}\left[I_1 e^{j(2\pi/\lambda)(L - z)} - RI_1 e^{-j(2\pi/\lambda)(L - z)} e^{j\delta}\right]. \tag{98}$$

In equation (98), I_1 represents the amplitude

of a wave traveling in the positive z direction, z is the running coordinate of the antenna with the feedpoint at the end $z = 0$, L is the length of the antenna, and RI_1 represents the amplitude of a return wave. Thus R is a reflection coefficient whose magnitude is less than unity, and δ represents a phase shift occurring at reflection. Thus I represents a return wave superposed upon a forward wave.

Now the angular dependence $E(\theta)$ of the

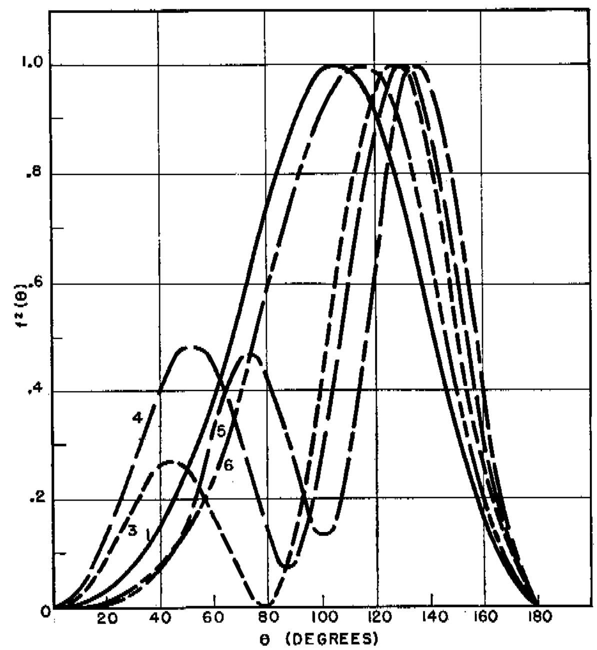

FIGURE 25. Directivity patterns at $W + 10$; longitudinal excitation; curve 1, M-30 100-lb bomb; curve 3, M-64 500-lb bomb; curve 4, M-64 1,000-lb bomb; curve 5, M-66 2,000-lb bomb; curve 6, M-81 260-lb bomb.

remote radiation field produced by a linear antenna of length L is given by

$$E(\theta) \alpha \sin\theta \int_0^L I(z) e^{[-(j2\pi/\lambda) z \cos\theta]} dz, \qquad (99)$$

where $I(z)$ is the current distribution along z.

It has been found that if $I(z)$ be taken as in equation (98), then normalized values of $E^2(\theta)$ obtained from equation (99) agree well with experimentally obtained patterns when R and δ are adjusted empirically. The picture of a forward wave and a return wave appears to be adequately correct to allow extrapolation and interpolation for changes in antenna size.

Small-Angle Radiation. Experimental measurement of patterns and the theoretical computations of patterns outlined above (see Section 2.10) both lead to the conclusion that, for small angles, we may express the directivity pattern as

$$f^2(\theta) = a \sin^2\theta, \qquad (100)$$

where a is a different constant for each projectile. This is a valuable generalization that facilitates computation of Z_r for cases arising in practice.

Effect of Projectile Geometry. Because of the considerable thickness of the projectile antennas, their physical lengths are considerably less than their "electrical" lengths. For a given physical length, an increase in thickness serves to increase the electrical length.

Effect of Tuning or Loading. The pattern depends only upon the frequency and the antenna geometry. There is, of course, no effect due to tuning or loading the antenna circuit.

COMPARISON OF PATTERNS FOR FUZE WORK

One of the desiderata of a proximity fuze is that it be usable without modification on various projectiles. It thus becomes necessary to examine, among other things, the variations in the directivity patterns for the various projectiles. This variation, for longitudinal excitation, has already been illustrated in Figure 25, where it is shown that at a particular frequency the patterns vary considerably. In the search for an optimum operating frequency for a proximity fuze for bombs, a large number of directivity patterns was taken at various frequencies for the several bombs and a comparison of $f^2(\theta)$ was made. In this comparison, relatively small values of θ are of importance in the ground-approach application since it is these that are encountered under terminal conditions for ordinary bomb releases. Because of the approximate law $f^2(\theta) = \alpha \sin^2\theta$, relative values for the various projectiles at one angle, i.e., $\theta = 30$ degrees, will hold, roughly, for smaller angles. Figure 26 presents the values of

$$\frac{M_0}{h} = \frac{\lambda}{4\pi} G f^2 \, (30°),$$

for various bombs for a range of frequencies. From Figure 26 it is seen that the expected

[redacted]

variation in signal covers a very wide range, except at frequencies of 50 mc and below. This agrees with the discussion in Section 2.5.6, which indicated that the signals for various bombs tend to approach the same level as the electrical length of the antenna is shortened below $\lambda/2$. Until close to the end of World War II it was not feasible to use frequencies as low as 50 mc, because the values of parallel radiation resistance encountered at these low frequencies (see Figure 15) would not permit efficient matching to the driving circuit, thus

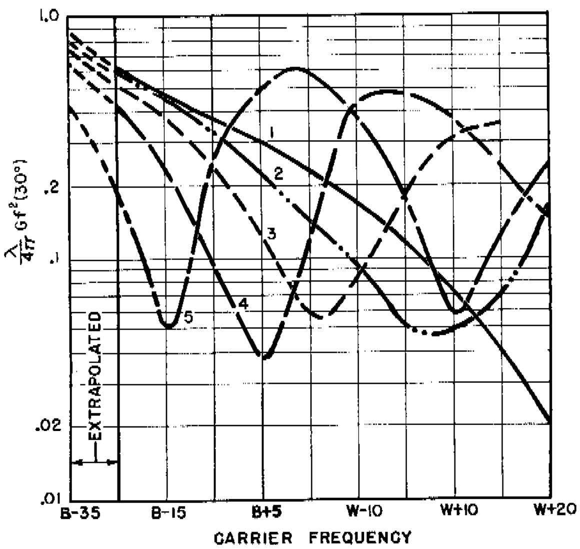

FIGURE 26. Relative signal strength $M_0/h = (\lambda/4\pi)\ Gf^2(\theta)$ at $\theta = 30°$, over a range of frequencies; longitudinal excitation; curve 1, M-30 100-lb bomb; curve 2, M-57 250-lb bomb; curve 3, M-64 500-lb bomb; curve 4, M-65 1,000-lb bomb; curve 5, M-66 2,000-lb bomb.

leading to low S values for high R_p. If the reflected signal is to be nearly the same at all heights for different projectiles using the same fuze, the product S_0M_0 must be constant. The term M_0 depends upon the directivity pattern and S_0 depends upon the operating point R_p. To hold the spread of S_0M_0 to reasonable values, it was found necessary to use two different radio frequencies in order to accommodate the fuze to various bomb sizes. It will be seen in Section 2.8.4. that transverse excitation largely avoids this difficulty. Toward the end of World War II a circuit was developed which could be matched to the high values of parallel radiation resistance encountered at low carrier frequencies. This made possible the design of a more nearly universal longitudinal excitation fuze for bombs.[40]

2.8.3 Transverse Excitation

TRANSVERSE DIPOLE

Fuzes working on this principle use a short transverse dipole as an antenna. The body of the projectile is not intentionally used as a part of the fuze, although it introduces complications as shown in Section 2.5.4. Space limitations are such that the transverse dipole is short compared to a half wave, and the directivity pattern tends to be like that for a short thin wire antenna, $f^2(\theta) = \sin^2\theta$ (see Figure 24). The close presence of the body of the projectile modifies the pattern so that it is no longer a figure of revolution about the antenna axis. In some cases the projectile acts like a director, making the radiation toward the back of the projectile greater than toward the front. A certain amount of asymmetry with respect to the bomb axis is sometimes present because of a slight unbalance in the feed.

An unbalanced feed for the transverse dipole, aside from the effects discussed in Section 2.5.4, gives rise to a directivity pattern which does not have axial symmetry. In Section 2.5.4 it was seen that the longitudinal currents give rise to a correction which is small if the longitudinal currents are kept small.

To verify the fact that these currents are small the radiation pattern of the fuze-projectile combination is measured with equipment arranged similarly to that shown in Figure 17. The projectile axis is horizontal and the axis of the transverse dipole is vertical. The receiver, which is sensitive only to horizontally polarized radiation, does not receive the energy radiated by the transverse currents flowing in the fuze dipole and the projectile behind it. It receives only the radiation from the longitudinal currents and gives a pattern like those for axial feed (see Figures 21, 22, 23, and 25).

The strength of the axial radiation is compared with the strength of the dipole radiation by putting the fuze dipole in the horizontal position and pointing the projectile directly toward

or away from the receiver. In this orientation the longitudinal currents do not radiate toward the receiver, and the received signal is that from the transverse dipole alone, modified by the reflecting properties of the projectile. As a result of the two measurements, two field intensities are obtained which show the relative amounts of energy radiated by the longitudinal and transverse currents. In order to suppress the longitudinal currents it has been found necessary to use a relatively long wavelength so that the projectile is nonresonant.

When the directivity pattern is measured with fuze dipole horizontal and projectile horizontal, an asymmetric pattern like that in Figures 27 and 28 is obtained. The right-left asymmetry arises from the addition of the patterns from longitudinal and transverse currents. The fore-aft asymmetry arises from the reflecting properties of the projectile. For short projectiles (see Figure 27) the fore-aft asymmetry is less marked than for larger ones.

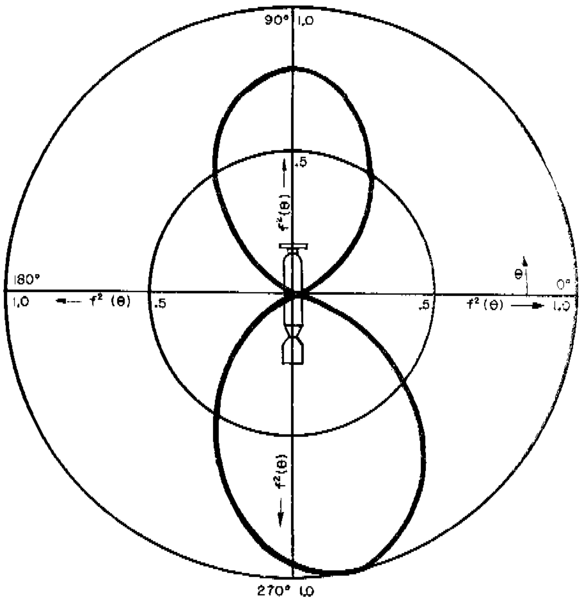

FIGURE 27. Directivity pattern for M-57 bomb at $W + 35$; transverse excitation; pattern taken in plane determined by longitudinal axes of dipole and bomb.

As we have seen, if the longitudinal current is small its effects can be neglected. Thus, to a good working approximation, we can take the directivity in the directly forward direction to be unity and the directivity in other directions forward of the equatorial plane as $\cos^2 \alpha$ or $\sin^2 \theta$.

When the transverse dipole is used, the size of the projectile has but little effect on the radiation resistance, provided the diameter is not too large and the projectile does not form an effective shield by imaging the dipole. This type of antenna is effective on all types of American bombs which the fuze will fit. It is not satisfactory with the British-type square-nosed bombs like the 4,000-lb LC, since this kind of bomb forms an effective shield unless the fuze is mounted on an extension. The British have found by extensive tests that a short extension makes the fuze quite satisfactory on this bomb.

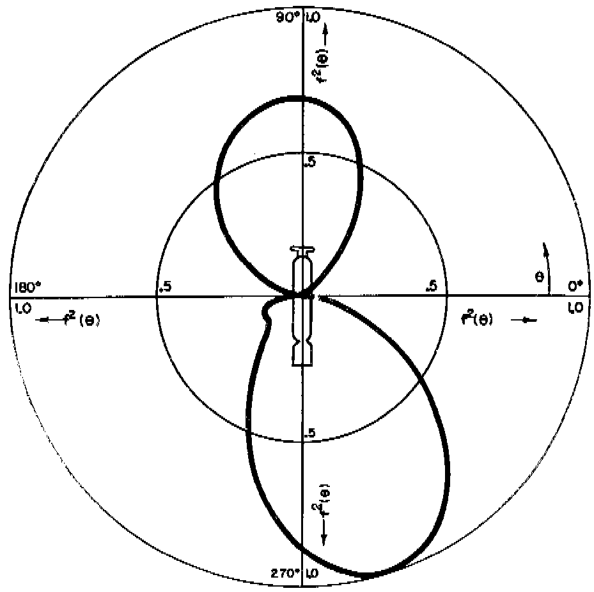

FIGURE 28. Directivity pattern for M-64 bomb at $W + 35$; transverse excitation; pattern taken in plane determined by longitudinal axes of dipole and bomb.

Furthermore, the vehicle has only a relatively minor effect on the pattern, as we have seen, so that the fuze operation becomes relatively independent of the size of the projectile. In addition, the transverse type of excitation will operate with nonconducting projectiles, such as the plywood belly tanks arranged with bomb fins used as fire bombs.

Loop Excitation

It is possible to obtain transverse excitation by means of a transverse magnetic dipole. This

is achieved by means of a small loop antenna, about 3 in. in diameter, whose plane includes the axis of the projectile, as in the T-172 fuze. The polarization of the radiation is different from that of an electric dipole, as shown by Table 2.

TABLE 2. Polarization of radiation in loop and dipole fuzes.

	Dipole	Loop
E_r	0	0
E_α	$\frac{A}{r}\cos\alpha\cos\delta$	$\frac{A}{r}\sin\delta$
E_δ	$\frac{A}{r}\sin\delta$	$\frac{A}{r}\cos\alpha\cos\delta$

The coordinate system for Table 2 is as defined in Section 2.5.4. Aside from the polarization change the argument is similar to that outlined for the transverse dipole, including unbalance effects. Similar radiation measurements are required, with due consideration for the polarization.

2.9 WORKING SIGNALS; GROUND-APPROACH CASE[e]

This chapter is primarily concerned with the variations of antenna impedance as the fuze approaches a reflecting target. This variation has been described by M, and the variation of M from point to point in space has been called the M wave. It has also been shown that the voltage change dV out of the r-f system can be specified in terms of circuit parameters.

$$dV = MS. \tag{89}$$

In other words, the voltage out of the r-f system is proportional to M, and in so far as relative wave form and amplitude are concerned M can be considered as a working signal set up by the reflecting target. Chapter 3 deals with the properties of circuits and the values of S that can be achieved.

The method of utilization of this signal has been indicated in Chapter 1 and will be briefly recapitulated here. The voltage dV is applied to an amplifier; the output of the amplifier is applied to the grid of a thyratron; when the output of the amplifier is of the proper magnitude and phase the thyratron discharges through a detonator which initiates the firing train resulting in the burst. In most cases the transmission time of the signal through the fuze and detonator are negligible. A treatment of the delay to be expected is given in Chapter 3, which deals with the audio amplifier and firing circuit. Since delays are generally small, the basic problem of the design is to make the output voltage of the amplifier reach the firing level at the moment when the projectile is in a position such that its burst would do the maximum amount of damage. While the necessary adjustments could be made empirically upon the basis of field trials, it is extremely helpful to be able to predict the expected point of function from the fuze parameters and the ballistic problem. Such a knowledge allows treatment of many cases based upon performance in a typical case; it also aids recognition of abnormal performance.

We proceed to show how the prediction is made for the case of a bomb approaching the ground. For the sake of clarity we first treat a special case in Section 2.9.1 and then turn to a discussion of each of the factors involved in Section 2.9.2.

2.9.1 Prediction of Height of Function

The case selected is that of the ring-type fuze (longitudinal excitation and White frequency band) on the M-64 (500-lb) bomb, released from level flight by an airplane flying at 200 mph from an altitude of 10,000 ft over earth which has a reflection coefficient of 0.5.

The equation governing this case, equation (93), has been derived in Section 2.6.2. Utilizing it, we have

$$dV = MS = \frac{\lambda n S_0}{4\pi h} G f^2(\theta,\phi) e^{j[(-4\pi h/\lambda) + \delta - \eta]}. \tag{101}$$

Equation (102) represents an audio-frequency voltage with peak amplitude

$$M_0 S_0 = \frac{n\lambda S_0}{h}\frac{G}{4\pi} f^2(\theta,\phi), \tag{102}$$

and frequency

$$F = \frac{1}{2\pi} \times \frac{4\pi}{\lambda}\left|\frac{dh}{dt}\right| = \frac{2}{\lambda}\left|\frac{dh}{dt}\right|. \tag{103}$$

[e] Bibliographical references pertinent to this section are 12, 16-22, 27, 35, 39, 40, 70, 71, 74.

[redacted]

For a falling bomb dh/dt is essentially constant over the last few hundred feet of flight, and we can take dh/dt as the vertical component of the striking velocity. Thus equation (101) represents a voltage of constant frequency and rising amplitude in the range in which there is appreciable reflected signal.

Let us assume that the steady-state voltage amplification of the amplifier is known in the form of a curve $g(F)$, henceforth denoted simply by g and that the net holding bias of the firing thyratron is B. Then we can say that the height of burst h is approximately

$$h = \lambda n S_0 \frac{G}{4\pi} f^2(\theta,\phi) \frac{g}{B}. \tag{104}$$

Equation (104) is based upon the tacit assumption that there is no delay in the amplifier and detonator, and further it ignores the fact that the thyratron can only fire when the voltage is positive, thereby introducing an uncertainty in the height of operation of approximately $(\lambda/2)$. The nature of these corrections will be discussed in more detail in Section 2.9.2.

The quantity B/g represents the peak voltage into the audio-control circuit that is necessary to fire the detonator.

We now insert appropriate values in equation (104) for our special case as follows: $G/4\pi = 0.208$, the vertical component of striking velocity $= 740$ fps, and the striking angle $= 18.5$ degrees, the wavelength $= 8.2$ ft, and $f^2(18.5 \text{ degrees}) = 0.085$. The audio frequency F is $(2 \times 740)/8.2 = 180$ c. Typical values of G, B, and S_0, are 80, 4.4, and 15, respectively. Using these values, equation (104) gives $h = 20$ ft.

This is the height of burst to be expected if only radiation fields are involved. Actually the induction field introduces a correction, as shown in Section 2.10, when the magnitude of h approaches λ.

2.9.2 Factors Affecting Magnitude and Frequency of Impedance Signal M

Having taken a brief overall view of the various factors determining the point of function of a fuze by computing the position of the burst in a typical case, we shall now discuss in more detail the various factors affecting the impedance signal M. We use the term "signal" advisedly, because the impedance change is dependent upon the interaction between fuze antenna and target, and therefore contains intelligence as to the conditions of such interaction.

The amplitude and frequency of the impedance signal or M wave depend upon a variety of conditions, some of which depend upon the fuze design and the projectile on which the fuze is used, others depending on ballistics and reflecting properties of the target. We shall omit factors depending upon the circuit adjustment, which is the subject of the next chapter. Aside from these the factors affecting M may be grouped according to the following scheme.

Fuze antenna factors

1. Directivity pattern.
2. Antenna gain.
3. Carrier frequency.

Ballistic and target factors

1. Distance from target.
2. Orientation of fuze antenna relative to target.
3. Speed of approach to target.
4. Reflecting properties of target.

We shall discuss each of these factors in turn.

Fuze Antenna Factors

Directivity Pattern. It has been shown, equation (93), that M is proportional to $f^2(\theta,\phi)$; the values of θ and ϕ in question are those obtained by drawing a straight line from the antenna perpendicular to the ground.

The nature of the patterns in use has been discussed in Section 2.8, where there was also presented a series of typical patterns. Upon referring to these patterns, it is evident that in the case of longitudinal excitation $f^2(\theta)$ is relatively small when the projectile is vertical or nearly vertical to ground, and becomes larger as the projectile becomes more nearly parallel to the ground.

In the case of transverse excitation, on the other hand, $f^2(\theta,\phi)$ is large when the projectile is normal to the target surface. When the angle between the surface and the axis of the projectile is any value other than 90 degrees,

there is an uncertainty in the value of $f^2(\theta,\phi)$ due to the uncertainty in orientation of the dipole antenna, as discussed in Section 2.5.4. If the angle between the axis of the projectile and the normal to the ground (angle of incidence) is α, then θ may be any value in the range (90-α) degrees to 90 degrees.

For most applications, the angle of incidence α is less than 45 degrees. This means that the terminal values of $f^2(\theta,\phi)$ obtained with the bar-type fuze, transverse excitation, are generally greater than those obtained with the ring-type fuze. Furthermore, $f^2(\theta,\phi)$ is generally a slower function of θ in the region 45 to 90 degrees than in the region 0 to 45 degrees, so that the average values obtained with the bar type depend less upon angle than with the ring type. At any one angle of incidence, however, the signal received by the bar-type fuze on a particular projectile tends to have a larger spread than for the ring type, because of the spread in dipole orientation mentioned above.

Antenna Gain. The equation (93) shows that M is proportional to the gain G of the fuze antenna. The values of G obtainable with present designs are relatively low, in the range 1.5 to 3. For an infinitesimal antenna $G = 1.5$, and for a half-wave dipole $G = 1.64$. To get highly directive antennas the frequency used would have to be very much higher than used at present, because of the small allowable physical dimensions of the antennas. Because of this, the antenna gain to date has not been a major design factor.

Carrier Frequency. From equation (103) it is seen that the audio frequency of the impedance change is proportional to the carrier frequency. The amplitude of the impedance change is also affected by the carrier frequency, since M is proportional to λ. Thus M is inversely proportional to the carrier frequency, while the audio frequency is directly proportional to the carrier frequency. Besides these direct effects, the carrier frequency affects M indirectly through its influence upon the directivity pattern (see Figure 23) and upon antenna gain. In addition to these important effects upon the impedance signal, it should be noted that the carrier frequency also affects the circuit efficiency and antenna matching, thus altering the values of S that can be achieved. This, however, is the subject of another chapter.

There is a discreteness in the possible firing positions introduced by the use of the thyratron control circuit. The spacing of these discrete positions is determined by the carrier frequency. Figure 29 shows how the discreteness arises.

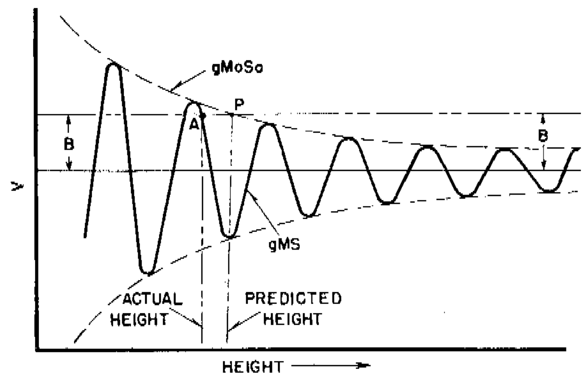

FIGURE 29. Illustrating the discrete character of possible firing positions. Signal voltage is plotted against height.

The solid curve represents the voltage out of the amplifier which is gMS having the dotted envelope gM_0S_0. The horizontal line B represents the holding bias. The point P, at which the envelope intersects the holding bias line, represents the point of function predicted by equation (105). The fuze actually functions when the M wave intersects the bias line at A a fraction of a cycle later. The positive peaks of the M wave occur for each $\lambda/2$ reduction of the height. For a particular fuze the size of the M wave might be such that it just passes over one positive peak. The predicted height of function would lie near this peak but the actual function would not occur until near the next peak about $\lambda/2$ further along. If the random variation of fuze sensitivities is larger than the change from one wave to the next, we will expect a random height of burst with bunches located at positions roughly $\lambda/2$ apart. Thus the carrier frequency determines the separation of the discrete function positions.

This discreteness has been observed in field trials. It implies that the average height of function should be about ($\lambda/4$) less than the predicted height.

BALLISTIC AND TARGET FACTORS

Distance from Target. It has already been shown that the magnitude of M is inversely proportional to the distance h of the fuze antenna from ground. (This has been derived from the consideration of the radiation field alone and is not valid for distances close enough so that the other components of the field are important. The modifying effect of these components is considered in Section 2.10.) Thus a plot of the resistance component of the reflected impedance versus h will take the form of a hyperbola, upon which is superposed a sinusoidal variation of space wavelength $\lambda/2$ and another variation according to the changes in $f^2(\theta,\phi)$ as the fuze moves along its trajectory. This latter factor is essentially constant over the working range of any particular trajectory for the ground-approach application.

Orientation of Fuze Antenna Relative to Target. The part played by the directivity patten has already been described. The ballistics of the situation, however, determine θ and ϕ and, therefore, the use to which the directivity pattern is put.

Because of a certain amount of rotation of the projectiles in flight, ϕ is generally indeterminate; for the ring type this is of no consequence, since the directivity patterns have cylindrical symmetry. The value of $f^2(\theta,\phi)$ for the bar-type fuze suffers a certain amount of indeterminacy as we have seen.

For bombs released from flight, the angle of incidence α increases as the speed of release increases and as the height of release decreases. This applies to dive bombing as well as release from level flight.

For projectiles fired from ground, α increases as the angle of elevation decreases. The speed of projection also plays a part.

In all cases the ballistic properties of the projectiles influence α in some degree because of the effect of air resistance. Tables of incidence angle α and vertical component of striking velocity are too lengthy to be included here. They may be found in standard bombing tables or in special tables prepared for use with VT fuzes.[18-21, 70, 71, 74]

Speed of Approach to Target. It has already been shown that the audio frequency is proportional to dh/dt, the speed of approach to the target surface. This speed of approach is determined by the release conditions of the projectiles (angle, speed, and height) and by their ballistic properties, and is essentially constant over the last few hundred feet of flight.

Now it happens that α and dh/dt are sometimes so related that proper shaping of the amplifier can be utilized to make up for wide variations in α over a range of conditions, with the result that the height of function remains fairly constant over the range. This is considered in detail in Section 3.2.

Because of the usually high speed of approach to the target, the amplitude of the M wave increases rapidly as the fuze nears the point of burst. Since the impedance changes are converted to voltage changes and then impressed upon an audio-frequency amplifier, it becomes important to take the dynamic character of the signal into account in order to determine the output of the amplifier. This matter has been the subject of considerable study and will be discussed in Chapter 3. As already indicated, it can be stated that to a sufficiently good approximation we can usually utilize the steady-state characteristics of the amplifier in computations of the function point of the fuze.

The terminal values of dh/dt encountered in the ground-approach applications range from about 200 to 1,200 fps.[18] Over the range of carrier frequencies 40 to 150 mc, this represents a range in audio frequencies of 16 to 360 c. Only part of this range is encountered in any one application.

Reflecting Properties of Target. The reflection coefficient n has already been defined in Section 2.5.1. Using this definition the impedance signal received from various types of surface is proportional to n. Before going further the method of measuring n for various types of ground will be described briefly. The apparatus consists chiefly of an antenna similar to a longitudinally excited bomb, fed by a load-sensitive oscillator. When the height of the antenna above the reflecting ground is varied the radiation impedance of the antenna changes, these changes affecting the grid voltage of the oscillator in a manner given by equations (89)

and (93). The amplitude of the fluctuations about the center value of grid voltage are recorded. These fluctuations are then compared with those obtained in a similar experiment with a large metallic screen for ground. Since the metallic screen is practically a perfect reflector ($n = 1$), the effective reflection coefficient of the ground is given by the ratio of the voltage fluctuations for the two types of reflector at the same height above each. Caution must be observed, in making these measurements, to use a large enough screen. The screen dimensions must be large compared to the maximum height used if complicated diffraction effects are to be avoided.

The results thus obtained check well when used to compute the actual magnitude of the signal instead of ratios. They also check with published values of the reflection coefficient for plane waves.[17, 27]

Table 3 shows the effective reflection coefficients of several types of surface.

TABLE 3. Reflection coefficient n.

Surface	n
Fresh water	0.8
Salt water	0.95
Average earth	0.5-0.6
Ice	0.2

If the ground surface is smooth, the value of M is proportional to the reflection coefficient n defined above. For the reflection coefficient n to apply, the surface must be fairly homogeneous. Irregularities, such as stones, that are small compared with the wavelength will have little effect upon M when the fuze antenna is at least several wavelengths away. Areas, such as puddles, that have a different reflection coefficient from the major part of the ground will likewise have little effect, if they are small compared to the height of function; a sort of average reflection coefficient is involved in such cases.

The effect of superposed targets, such as ice over water, must be considered. Penetration of the radio waves at the frequencies used is quite small for metal, sea water, fresh water, dry sand, and ordinary soil. Penetration into ice or snow is considerably greater. Water a few inches deep over a considerable area of land or ice acts like a water target because of its small penetration of the waves into water. A layer of ice or snow that is only a few inches thick gives a reflection coefficient more nearly that of the surface beneath it than of ice or snow.

The effect of a general slope in the target area is equivalent to a different angle of fall over level ground.

The effects of large surface irregularities are complicated and must be evaluated empirically. When the fuze passes close to a large body, such as a building, the reaction is similar to that from an airborne target (treated in Section 2.11), and the burst occurs near the obstruction.

The effect of built-up areas like cities on the height of burst is not yet well known. However, some general remarks can be made. The general average reflection coefficient n will be lower than for moist earth, i.e., about 0.4. In general it is expected that the *average* height of burst will be greater than that predicted on the basis of the average n; the difference is about half the *average* height of the structures. The dispersion in height of burst will, of course, be considerably increased.

The height of burst over densely wooded areas has been found by experience to be just below the level of the treetops for longitudinal fuzes. Not much is known about transverse fuzes under this condition.

When the fuze passes near the edge of a cliff, it functions in a manner similar to the airborne-target case. When it passes over a boundary between two different reflecting media such as water and sand, there is a change in M which is rapid if the fuze passes close to the boundary and slower if the distance is larger. Whether or not the transition causes a burst will depend upon the transient response of the amplifier and the abruptness of the transition between reflectors.

2.10 EFFECT OF INDUCTION FIELD ON CLOSE FUNCTIONS[f]

The preceding analysis of the reflected impedance, based solely upon the radiation fields

[f] Bibliographical references pertinent to this section are 12, 23-26, 39, 40, 94.

[redacted]

from the antennas involved, would indicate that there is no change in reflected impedance for the case of a longitudinally excited fuze approaching the ground in a vertical direction since $f^2(\theta) = 0$. However, a little thought will show that this is contrary to the principle of conservation of energy. Therefore we must call upon those fields in the vicinity of the antenna which die away as the square of the distance and the cube of the distance in order to describe the behavior of the fuze near the ground.

This can be seen as follows. If we use the same argument as used in Section 2.14 with the dipole oriented with its axis vertical, we find that the total power radiated through the upper infinite hemisphere varies with the height of the dipole. These variations must appear as a variation of radiation resistance and hence give rise to an M signal. The higher-order terms appearing in equation (160) (see Section 2.14) represent the effect of these nearby fields for the special case of the short horizontal dipole. It should be stressed that the calculation is made in terms of radiation fields alone but that the results are identical with a treatment based upon the induction and quasi-static fields.[23]

If attempts are made to extend this method to the more complicated radiation patterns of typical fuzes approaching at different angles, the necessary integrals become impossibly complicated and it is more convenient to use the actual fields to calculate the result.

2.10.1 Second Approximation to the Field Equations

In the previous discussion it was possible, by restricting attention to $1/r$ radiation fields alone, to avoid any reference to the current distribution of the antenna and its coupling to the feed system. In the argument which follows it will be necessary to assume a current distribution of a form which will give rise to the observed radiation pattern and to consider the interaction of this current with the reflected fields. We shall be interested in the case of a fuze approaching an infinitely reflecting ground. The case of the airborne target does not, in most cases, involve the nearby fields to a serious extent and has not been considered from this point of view. As has already been shown we deal only with the fuze and its image to derive the necessary impedance change.

The problem thus becomes one of calculating the mutual impedance of two identical antennas

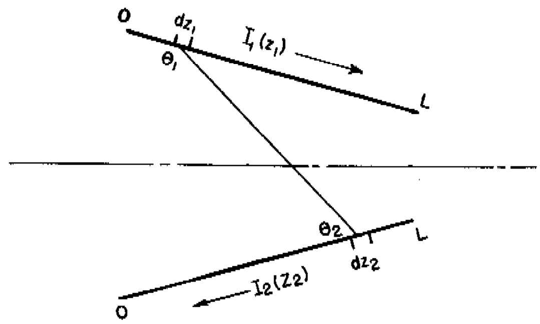

FIGURE 30. Representation of fuze antenna and its image.

oriented as shown in Figure 30. In this figure we assume that the current distribution on each antenna is given by

$$I_1(z_1) = I_{10}g_1(z_1), \tag{105}$$

$$I_2(z_2) = I_{20}g_2(z_2), \tag{106}$$

where I_{10} and I_{20} are the currents at the feed points. We are forced to assume that the presence of either antenna does not alter the current distribution on the other and that both are identical, except for a 180-degree phase shift, and the same as the distribution when each antenna is radiating into free space.

Now the current $I_1(z_1)$ gives rise to a field $E_{21}(z_2)$ parallel to antenna No. 2 and vice versa. Following Carter[94] we write for the mutual impedance

$$Z_{12} = -\frac{1}{I_{10}} \int_0^L E_{21}(z_2) g_2(z_2) dz_2. \tag{107}$$

We first examine E_{21}. For an infinitesimal dipole of length dz, the field at distance r is given by

$$\begin{aligned} E_\theta &= \frac{bI dz}{\lambda r} \sin\theta \left[1 - \frac{j}{\beta r} - \frac{1}{(\beta r)^2}\right] j e^{j(\omega t - \beta r)}, \\ E_r &= \frac{bI dz}{\lambda r} \cos\theta \left[-\frac{2j}{\beta r} - \frac{2}{(\beta r)^2}\right] j e^{j(\omega t - \beta r)}, \\ E_\phi &= 0, \end{aligned} \tag{108}$$

where $\beta = 2\pi/\lambda$ and b is a constant. At suffi-

[redacted]

ciently large distances the higher orders of $(1/r)$ can be neglected, thereby making E_r negligible and

$$E_\theta = \frac{bIdz}{\lambda r} \sin \theta j e^{j(\omega t - \beta r)}. \tag{109}$$

It was this field that was used in the previous analysis and called the radiation field, since it accounts for the average radiated energy. The other terms, in the integration of the Poynting vector, give fluctuating components of energy with no net energy flow.

The above expressions pertain to an infinitesimal antenna. The fields due to a finite antenna may be obtained by regarding the antenna as composed of infinitesimal antennas and integrating the fields due to the individual infinitesimal antennas.

For a finite linear antenna placed along the z axis, we have

$$E_\theta = \int \frac{b \sin \theta}{\lambda r} j e^{j(\omega t - \beta r)} \left[1 - \frac{j}{\beta r} - \frac{1}{(\beta r)^2}\right] I(z)dz, \tag{110}$$

with a similar integration for E_r. The integral sign here denotes the limit of a vector summation over the whole antenna.

Now r and θ are in general functions of z. For points sufficiently distant from the antenna, the dependence of θ upon z is sufficiently slow that it may be neglected. For comparatively large distances the r dependence upon z may be neglected in so far as the amplitudes of the contributions of the individual elementary antennas are concerned; because of the finite propagation time, however, the individual contributions vary in phase. These phase variations cannot be neglected. Taking into account the above considerations, the components of the electric field may be expressed as follows:

$$E_\theta = b \frac{j e^{j(\omega t - \beta r)}}{\lambda r} \left[1 - \frac{j}{\beta r} - \frac{1}{(\beta r)^2}\right] \cdot \sin \theta \int_0^L e^{-j\beta z \cos \theta} I(z)dz, \tag{111}$$

$$E_r = b \frac{j e^{j(\omega t - \beta r)}}{\lambda r} \left[-\frac{2j}{\beta r} - \frac{2}{(\beta r)^2}\right] \cdot \cos \theta \int_0^L e^{-j\beta z \cos \theta} I(z)dz. \tag{112}$$

In the above expressions the factor $e^{-j\beta z \cos \theta}$ takes into account the phase variations just discussed, since $z \cos \theta$ is the path difference for contributions from $z = 0$ and $z = z$. The r in the above equations is the distance from the point $z = 0$ to the point P, where the field is calculated. The term $I(z)$ represents the z dependence of the antenna current over its length L.

If we denote the remote radiation field of the finite antenna by E_{rad}, equations (111) and (112) may be modified as follows:

$$E_\theta = \left[1 - \frac{j}{\beta r} - \frac{1}{(\beta r)^2}\right] E_{\text{rad}}, \tag{113}$$

$$E_r = \cot \theta \left[-\frac{2j}{\beta r} - \frac{2}{(\beta r)^2}\right] E_{\text{rad}}, \tag{114}$$

$$E_{\text{rad}} = \frac{b}{\lambda r} j e^{j(\omega t - \beta r)} \sin \theta \int_0^L e^{-j\beta z \cos \theta} I(z)dz. \tag{115}$$

For thin antennas, sinusoidal current distributions are often assumed as engineering approximations; the integration may be effected under this assumption, giving well-known formulas for E_{rad} for such cases.

For the fuze antennas, the current distributions are ordinarily not known with sufficient precision to allow the carrying out of this integration. The θ dependence of $|E_{\text{rad}}|$ is obtained experimentally by the method described in Section 2.8.2. Thus the $f(\theta)$ used there is given by

$$f(\theta) = \left|\sin \theta \int_0^L e^{-j\beta z \cos \theta} I(z)dz\right|. \tag{116}$$

The experimental method gives only the absolute value as indicated and not the phase dependence on θ which is ordinarily not needed.

To get E_{21} from E_r and E_θ we use

$$E_{21} = E_{\theta 1} \sin \theta_2 + E_{r1} \cos \theta_2. \tag{117}$$

The restrictions which allowed us to write equations (113) and (114) also imply that $\theta_2 = \theta_1$ and that both are sufficiently independent of z_1 and z_2. Thus we write

$$E_{21} = E_\theta \sin \theta + E_r \cos \theta = E_{21}' e^{j(\omega t - \beta r)}, \tag{117a}$$

which defines E_{21}' as a function which is independent of z. In the exponential term r is the

[redacted]

distance from $z_1 = 0$ to the point z_2 on antenna No. 2. Thus the mutual impedance becomes

$$Z_{21} = -\frac{1}{I_{10}} E_{21}' \int_0^L e^{-j\beta r}\, g_2(z_2) dz_2. \qquad (118)$$

Again we must take account of phases, and so we denote $\overline{r}$ as the distance between the point $z_1 = 0$ on antenna No. 1 and the point $z_2 = 0$ on antenna No. 2. In this notation $r = \overline{r} + z_2 \cos\theta$, and we can further simplify equation (118) to get

$$Z_{21} = -\frac{1}{I_{10}} E_{21}' \, e^{-j\beta \overline{r}} \int_0^L e^{-j\beta z_2 \cos\theta}\, g_2(z_2) dz_2. \qquad (119)$$

If we neglected all induction fields in the calculation of equation (119), the only change would be that E_{21}' would reduce to $E'_{\text{rad}} \sin\theta$ where E'_{rad} is defined in the same manner as E_{21}'. If we call the result of such a calculation $Z_{21_{\text{rad}}}$, we have

$$\frac{Z_{21}}{Z_{21_{\text{rad}}}} = \frac{E_{21}'}{E'_{\text{rad}} \sin\theta}, \qquad (120)$$

or, since M_0 is proportional to Z_{21}, we may write

$$\frac{M_0}{M_{0_{\text{rad}}}} = \frac{|E_{21}'|}{|E'_{\text{rad}} \sin\theta|}. \qquad (120a)$$

Comparison of equations (113), (114), (120), and (121) shows that

$$\frac{M_0}{M_{0_{\text{rad}}}} = \sqrt{\left[1 - \frac{1}{(\beta r)^2} - \frac{2}{(\beta r)^2}\cot^2\theta\right]^2 + \left[\frac{1}{\beta r} + \frac{2}{\beta r}\cot^2\theta\right]^2},$$

which reduces to

$$\frac{M_0}{M_{0_{\text{rad}}}} = \left[1 - \frac{1}{(\beta r)^2}(4\cot^4\theta - 1)\right]^{\frac{1}{2}}, \qquad (121)$$

after expanding and dropping inverse fourth-power terms in r.

2.10.2 Effect of Induction Field on Function Heights

Equation (121) is a second approximation to the calculation of Z_{12}. It is not exact and is limited in its application to cases where the antenna is close enough to its image to make the nearby fields appreciable but not so close that the approximations used in deriving it break down. Thus it can be expected to give reasonably valid answers only for heights such that the antenna length is not a considerable fraction of the distance between it and its image. Moreover, the whole derivation is based upon a thin wire antenna as a model. The fat antennas actually used may alter conditions.

Actually, in spite of the limitations, the theory has been of considerable use in proper selection of fuze antennas and the selection of proper operating frequencies.

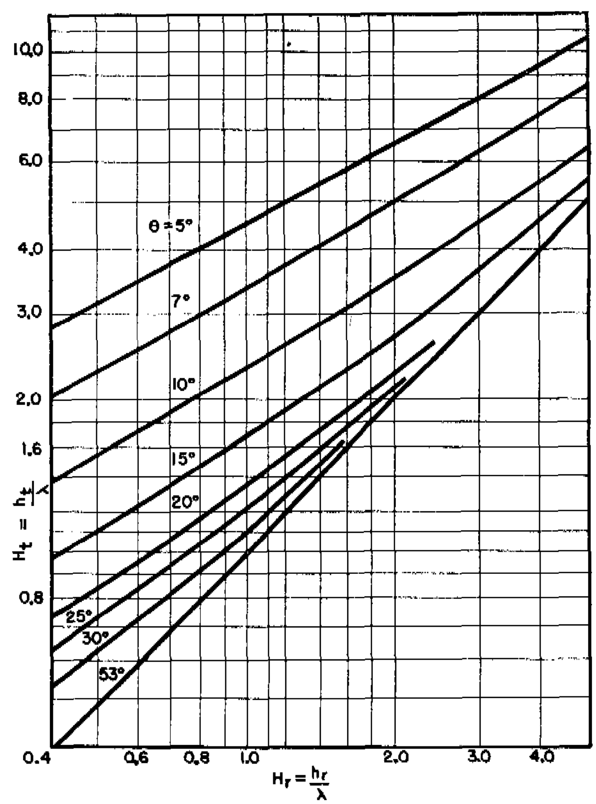

FIGURE 31. Contribution of induction and quasi-static fields to height of function; H_t as function of H_r for various values of θ.

Since $|dV|$ is proportional to M_0, we can then say

$$|dV_t| = |dV_r| \frac{M_0}{M_{0_{\text{rad}}}}, \qquad (122)$$

where $|dV_r|$ is the peak value of the voltage change into the amplifier that would be com-

[redacted]

puted from radiation fields alone and $|dV_t|$ is the total voltage change including the effect of nearby fields. If we now set $|dV_r|$ and $|dV_t|$ each equal to the signal magnitude required to actuate the fuze, B/g, the heights of function predicted with and without the correction terms, denoted by h_t and h_r respectively, are seen to be related as follows:

$$\frac{\lambda}{h_r} = \frac{\lambda}{h_t}\sqrt{1 + \left(\frac{\lambda}{4\pi h_t}\right)^2 (4 \cot^4 \theta - 1)}. \quad (123)$$

This relation is shown graphically in Figure 31 for several values of θ. This graph shows the contribution made by the induction and quasi-static terms to the heights of function. This contribution is seen to be significant when θ is small and when h_t/λ is small. For large values of θ and (h_t/λ) the correction becomes negligible.

If we use H_r as the height of function, expressed in units of λ as calculated without the correction, and H_t as the height of function in the same units and including the corrections, we may write

$$H_t = H_r\left[\tfrac{1}{2} + \tfrac{1}{2}\sqrt{1 + \frac{D}{H_r^2}}\right]^{\frac{1}{2}}, \quad (124)$$

where

$$D = \frac{4 \cot^4 \theta - 1}{4\pi^2}. \quad (125)$$

For a vertical approach $H_r = 0$, but the correction term becomes infinite leading to an indeterminate answer for H_t which must be evaluated by further means.

From equation (104) we see that

$$H_r = \frac{G}{4\pi} n S_0 \frac{g}{B} f^2(\theta). \quad (126)$$

Also from equation (116) we see that

$$f^2(\theta) = \left|\left[\sin\theta \int_0^L e^{-j\beta z \cos\theta}\, I(z)dz\right]\right|^2. \quad (127)$$

Since the integral is a slowly varying function of θ for small θ, we may write

$$f^2(\theta) = a \sin^2 \theta, \quad (128)$$

for very small angles. For any particular projectile the value of the constant a is determined experimentally from its measured directivity pattern. Combining equations (124), (125), (126), and (128), we get for very small angles

$$H_t \cong \sqrt[4]{\frac{DH_r^2}{4}}, \quad (129)$$

or

$$H_t \cong \sqrt{\frac{aGnSg}{8\pi^2 B}}. \quad (129a)$$

The latter value is independent of θ and sufficiently accurate for θ from 0 to 10 degrees. It is not valid for $H_t < 1$; in such cases the theory does not hold anyway, as has already been mentioned.

The equation (129a) is of interesting qualitative value, since it shows that the height of burst at very steep approach angles depends upon the slope a of the directivity pattern near $\theta = 0$ (slope on $\sin^2\theta$ paper). Thus directivity patterns like curves 5 or 6 in Figure 25 will give very low height of burst even with the aid of the induction field.

Figure 31 may be used to correct the heights of function computed on the basis of radiation alone. Referring to the example worked out in Section 2.9, we have $H_r = 20/8.2 = 2.4$. From Figure 31 we see that for $\theta = 18.5$ degrees and $H_r = 2.4$, $H_t = 2.7$, or $h_t = 22$ ft.

In this case the correction is not large. For steeper angles of approach the correction becomes more pronounced. If radiation calculations predict a height of 2λ for a striking angle of 10 degrees from the vertical, the actual burst height will be 3.5λ, a correction of +75 per cent.

A large amount of computation of heights of function has proved to be necessary. For this reason a method has been developed which greatly reduces the amount of labor involved, especially when rapid computations are needed in order to help design an amplifier with a shaping such as to give desired heights of function over a large range of ballistic and fuze conditions. This method involves the use of transparent charts.[39]

We see from equation (129a) that for steep approach the height of burst varies as the square root of the burst control factors, G, n, S, g, and $1/B$, and is thus less dependent upon variations in these quantities when burst

[redacted]

heights are such that the induction field is predominant.

A word of caution is necessary about incorporating amplifier delay to avoid noise troubles on fuzes where the induction field is the primary signal controlling the height of burst. Suppose, for example, we have a fuze on a small antenna so adjusted that $S = 15$, $g = 50$, and $B = 4.5$. Then for average ground $n = 1/2$, and for the small antenna $a = 1$ and $G = 1.5$. When these values are inserted in equation (129a) the result is

$$H_t = 1.3.$$

If the firing level of the amplifier lags as much as 3 c behind the calculated input firing level, the fuze will reach $H_t = 0$ before the burst is initiated, since there are 2 c of input voltage per λ change in height. Such delay may give rise to duds because the fuze breaks up before the firing pulse is received. This behavior has been observed in special fuzes carrying integrating circuits to increase the resistance to noise pulses and sweep jammer signals.

2.11 WORKING SIGNALS; AIRBORNE TARGET[g]

The preceding two sections have been devoted to an analysis of the signals encountered in the ground-approach case. The second important application of a radio proximity fuze is to initiate bursts in the vicinity of an airborne target. In the present section the signals occurring in this case will be studied.

To avoid complication we assume that the fuze and target are far from ground and understand that corrections may be introduced if they are near the ground (see Section 2.5).

It is, of course, to be expected that the reflection from so complicated a target as an airplane will indeed be complex and not amenable to exact analytic treatment. There are, however, certain general features of the problem, which can be discussed in terms of a simple model, that carry over into the actual problem. A knowledge of these features is essential to an understanding of the operation. In Section 2.11.1 we shall consider the target to be a small sphere which reflects equally in all directions. First we consider the changes in phase in the M wave and later the amplitude changes. Sections 2.11.2 and 2.11.3 will be devoted to a discussion of actual airplane targets. In all discussions we use a reference system at rest on the target.

[g] Bibliographical references pertinent to this section are 1, 14, 15, 55, 61, 72, 73, 75, 93.

2.11.1 Properties of the *M* Wave; Simple Theory

PHASE PROPERTIES

Figure 32 represents the spatial arrangement of fuze and target (a small sphere). In this

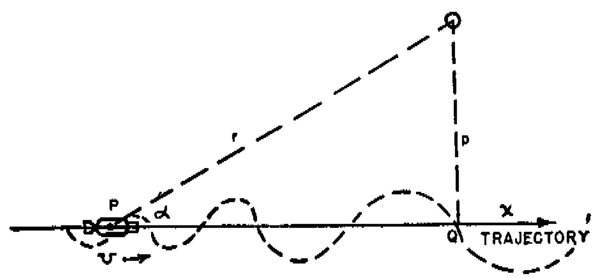

FIGURE 32. Spatial arrangement of fuze and small spherical target.

figure the axis of the projectile is shown as coinciding with the trajectory. This is, of course, not true in the general case but is close enough for the type of approach used in firing rockets in air-to-air combat, since deflection firing is seldom considered. The projectile is at P and is moving along the x axis in the direction of the arrow. The distance between projectile and target is r, and the shortest distance between the target and the line of flight of the projectile is p. The term p may be called the impact parameter as in similar situations in atomic physics. The line OQ is perpendicular to PQ. The distance from P to Q is x. The angle between PO and PQ is α. For fuze systems in which the body of the projectile is used as the antenna (longitudinal excitation), the angle α is the same as the θ previously defined. The relative velocity of the projectile along its line of flight is denoted by v.

To proceed further, we recall that for the case of reflection by a simple airborne target, the M wave is given by a function of the form

$$M = M_0 e^{j[(-4\pi r/\lambda) + \delta]}. \tag{130}$$

There may be a phase shift at reflection which will be a constant for the spherical target and will be neglected.

The frequency F of the M wave is

$$\begin{aligned} F &= \frac{1}{2\pi}\left|\frac{d}{dt}\left(\frac{4\pi r}{\lambda}\right)\right|, \\ F &= \frac{2}{\lambda}\left|\frac{dr}{dt}\right|, \end{aligned} \tag{131}$$

$$F = \frac{2v}{\lambda}\cos\alpha. \tag{132}$$

Thus the maximum possible value of the instantaneous frequency is $2v/\lambda$ when $\alpha = 0$ degrees when the target is very far away, and the minimum value is 0 when $\alpha = 90$ degrees. As the projectile approaches the target the frequency decreases; when the projectile is at the point of nearest approach to the target, the instantaneous frequency is zero.

The rate of change of instantaneous frequency with angle is given by

$$\frac{dF}{d\alpha} = -\frac{2v}{\lambda}\sin\alpha. \tag{133}$$

This equation indicates that the rate of change of instantaneous frequency increases as α approaches 90 degrees. For sufficiently large values of α, the rate of change of frequency with angle is great enough to cause a considerable change of instantaneous frequency during the course of 1 c. Thus it is important to introduce dynamic considerations when studying the response of an audio amplifier to such a signal.

It should be pointed out that there are in general only a relatively small number of waves of M in that part of the trajectory where the fuze is sufficiently near the target to be effective. Calculation gives the result that there are $0.8p/\lambda$ waves in the region from $\alpha = 45$ degrees to $\alpha = 90$ degrees.

For a typical case $\lambda = 8$ ft, $p = 50$ ft, and there are 5 c in the M wave. A longer wavelength means fewer cycles and requires more care in including dynamic considerations in the study of the behavior of an audio-frequency control circuit.

Caution must also be observed, in incorporating delay to avoid noise troubles and interference from jamming signals, to make sure that enough cycles are available to actuate the control circuit. Thus the higher the carrier frequency the larger the number of waves available and hence the better a control mechanism based on audio-frequency selectivity can be expected to function.

The manner in which the resistive component of the reflected impedance changes as the fuze antenna moves along its trajectory is shown qualitatively by the dotted line in Figure 32.

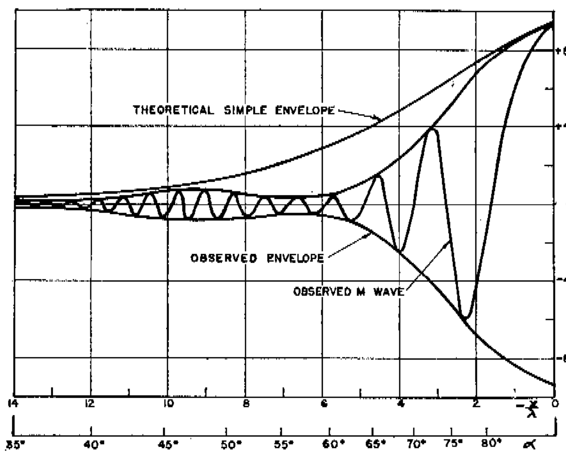

FIGURE 33. Typical experimentally observed M wave, with its envelope and theoretical simple envelope.

AMPLITUDE PROPERTIES

From equation (94) we see that

$$M_0 = A\,\frac{\lambda}{2\pi r^2}\,Gf^2(\alpha)\cos\tau. \tag{134}$$

Figure 33 shows a plot of M_0 for a spherical target with $f^2(\alpha)$ the actual measured directivity of a typical fuze. It is marked "theoretical simple envelope" on this figure. The ordinates represent the M signal in arbitrary units. There are two sets of abscissas, one set representing $-x/\lambda$, as defined in Figure 32, and the other set representing α.

It will be observed from equation (134) that, as the target is approached, M_0 increases as the square of the distance decreases and as the

directivity in the direction of the target increases. We shall expect this general sort of behavior even for a complicated target.

2.11.2 Reflecting Properties of Aircraft

When considering a complicated reflecting target like an airplane we shall expect a variable phase shift upon reflection. This we represent by assuming that A, as defined in Section 2.5.2, is complex and of the form

$$A = F(r,\theta,\phi)e^{j\delta(r,\theta,\phi)}. \tag{135}$$

At very large distances, such that the wave incident on the target can be considered plane, equation (135) will reduce to

$$A = F(\theta,\phi)e^{j\delta(\theta,\phi)}, \tag{136}$$

the $1/r$ dependence of reflected field being taken care of in the definition of A. At close distances the whole argument becomes too complicated to be within the scope of this report.

The variation in the phase of M arising from $\delta(\theta,\phi)$ will change the spacing of the zeros of M and thus alter the apparent instantaneous frequency in a complicated manner.

It is helpful to consider the airplane as a complicated antenna which is excited by the incident radiation and which reradiates with a many-lobed pattern characteristic of such an antenna. Whenever the direction of the incident radiation changes, the distribution of current on the aircraft changes and the radiation pattern is correspondingly altered. Moreover, if the source of radiation is close so that the field is not uniform over the target, the distribution of current will change with distance, also giving a change in the reradiation pattern.

We might expect that the dependence of A and δ upon r will disappear for distances r such that the target does not fill more than the first Fresnel zone. We define the first Fresnel zone in this case as that circular area such that the path from the fuze to the center of the area is $\lambda/4$ shorter than the path from the fuze to the outer rim. Experiments to be described later show that this is roughly borne out.

For frequencies of 100 mc and a target 50 ft across, the target just bridges the first zone at $r = 125$ ft. The radius of action of present-day fuzes is well inside this range, so that simple calculations can only give an order-of-magnitude effect. The actual values of M must be determined by experiment.

There is, however, one very important factor that minimizes the effect of the complicated reflection on fuze performance. The factor $f^2(\alpha)/r^2$ grows so rapidly with increasing α that there is a relatively small region in space around the target where the signal is large enough to actuate the fuze and the point of burst becomes relatively independent of the details of the wave form provided there are cycles enough to get through the amplifier.

Experimental Measurement of Reflection from Aircraft

The straightforward method of measuring the reflecting power from an airplane is to construct fuzes carrying radio reporting circuits and fire them past an airborne airplane. This gives the actual working signal but technical difficulties make such tests impossible at the present time.

For certain special interaction conditions the airplane can be flown past the fuze, which is held fixed in space. This gives information which is useful for head-on or tail-on shots in air-to-air combat; these are the most common shots where rockets are concerned.

Experiments have been made for these conditions in two ways. (1) The fuze was suspended beneath a blimp and the airplane flown by it. These tests gave reliable qualitative information about the signal voltages, but it was difficult to get the exact distance measurements required. (2) The fuze was supported at a height of $\lambda/4$ over a reflecting screen on the ground and an airplane flown over it.[1] These latter experiments were made at the Naval Proving Ground, Dahlgren, Virginia.

Properties of the Experimental M Waves

Some 50 space patterns were obtained from which quantitative measurements could be made. Parts of three typical patterns are shown in the oscillograms of Figure 34. In Figure 33 a typical experimentally obtained pattern is shown, together with its envelope, which is

compared with the theoretical simple envelope discussed above.

An analysis of the phase properties of the experimentally obtained waves gives very good agreement with the simple theory given in Section 2.11.1, showing that $\delta(\theta,\phi)$ is a slowly varying function and does not complicate the pattern.

The experiments also showed that the inverse square law holds. The upper curve in Figure 35

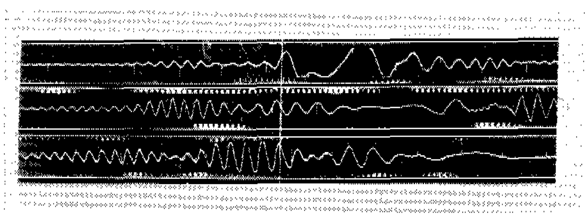

FIGURE 34. Oscillograms of parts of typical M waves in fly-over tests.

These oscillograms were obtained in tests in which an airplane flew over a fuze antenna mounted horizontally above the ground. In the figures time increases from the left to right. The vertical lines are timing pulses. The three oscillograms are parts of a large photograph discussed on page 23 of reference 1. Details of test conditions will also be found in this reference.

shows the results of a series of tests in which an SBD-1 airplane flew vertically over a fuze antenna; the plane was in horizontal flight parallel to the axis of the fuze antenna. The fuze antenna was a distance $\lambda/4$ above the screenwire ground. The ordinate in Figure 35 is the logarithm of the magnitude of the signal voltage ΔV, and the abscissa is the logarithm of the distance p. It is clear from the figure that the inverse square law holds for distances as close as 80 ft for $\lambda = 7.4$ ft as used.

From the Dahlgren experiments some quantitative comparisons were made of the reflection from the best aspect of the airplane and the reflection from a tuned half-wave dipole. The dipole was placed horizontally at various heights above the fuze antenna and turned about a vertical axis. As the dipole was rotated about a vertical axis, the reflected impedance M_0 changed from zero to a maximum value as $\cos\tau$ varied from 0 to 1. The signal magnitude at various heights was taken. Typical results are shown in the lower curve in Figure 35. The ordinate distance between the upper and lower curves in Figure 35 represent a ratio of 21; that is, the reflecting power of the airplane in the aspect considered is 21 times as great as that of a tuned half-wave dipole arranged for maximum reflection. It has already been mentioned in Section 2.5 that the reflecting power A_{max} of a flat plate of area L^2 is $L^2\lambda$, whereas that of a tuned half-wave dipole is 0.26λ. The projected area of the airplane, regarded as a flat plate, is about 300 sq ft. The wavelength λ used in this experiment was 7.4 ft. Then the ratio

$$\left(\frac{L^2/\lambda}{0.26\lambda}\right),$$

becomes 20.5, in satisfactory agreement with the experimental values.

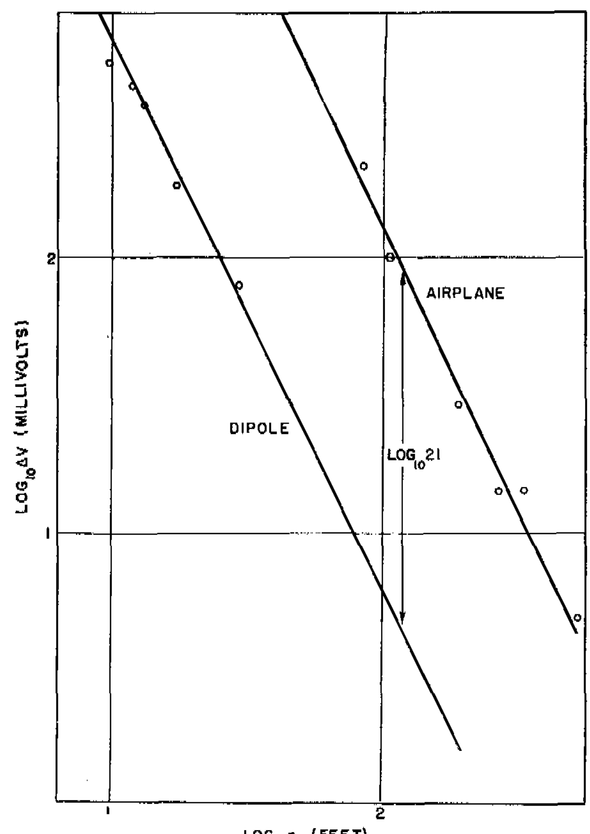

FIGURE 35. Signals from airplane and from tuned half-wave dipole.

Expressing the reflecting power of the aircraft in units of "dipoles" in the direction of maximum reflection has been convenient in engineering the fuze design. In the above de-

scribed experiment, the airplane is equivalent to 21 dipoles.

The envelope of the wavy curve in Figure 33 gives a rough idea of the variations in M_0 as the position of the fuze antenna changes with respect to the airplane target. This wave represents the signal received by a radio fuze on a rocket due to a small airplane passing the rocket at a distance p equal to about 15λ or 105 ft in this case. To indicate the extent to which the signal acts as would be predicted from a point target, an envelope computed according to the simple theory is plotted on the same graph. That is, the simple envelope is a plot of the equation

$$M_0 = \text{Constant} \times \frac{f^2(\alpha)}{r^2}, \tag{137}$$

whereas the observed envelope is effectively a plot of the equation

$$M_0 = \text{Constant} \times \frac{A f^2(\alpha)}{r^2}. \tag{138}$$

The two envelopes are adjusted so that their maximum values coincide. The observed envelope indicates the nature of the variation in A along the trajectory. It is clear from the figure that the simple features of the theoretical envelope are modified in the observed envelope, in that there is a minimum around $\alpha = 60$ degrees, whereas the amplitude of the theoretical envelope rises constantly as α increases toward 90 degrees.

Other patterns experimentally obtained for a variety of aspects and distances exhibit similar features, that is, a general trend as expected from the simple theory, plus a superposed effect of one or two minima. The positions of the minima vary with aspect and type of airplane. Thus the amplitude properties of the wave follow the simple theory to a certain extent; furthermore, as we have seen, the phase properties follow the simple theory quite well. Thus the characteristics of the wave are sufficiently well known to achieve good burst control, as will be shown in Chapter 3.

Specification of Sensitivity Requirements for Plane-to-Plane Rocket Fuze

We are now in a position to outline a sample calculation for a trial design center for a fuze for the plane-to-plane rocket application.

The fuze will fire when

$$M_0 = \frac{B}{S_0 g}. \tag{139}$$

Within engineering limits, the quantity B/S_0g can be varied at will, so we shall calculate the value of M_0 to be expected and leave the discussion of B/S_0g to appropriate chapters. The maximum value of M_0 has been seen to be equivalent to about 20 dipoles for the direction of best reflection from the airplane. We take the value of 10 dipoles as a working average.

From equation (49) we see that A for a single dipole is 0.26λ, and with the aid of equation (134) we find the reflection from a target of 10 dipole strength to be

$$M_0(90°) = \frac{2.6\lambda^2 G}{2\pi p^2} f^2(90°),$$

at the point of maximum reflection from the target. For a typical fuze with a half-wave antenna $G = 1.64$, $f^2(90°) = 1$, and $\lambda = 7.5$ ft. If we wish the fuze to function up to a distance of $p = 10\lambda$,

$$M_0(90°) = \frac{2.6 \times 1.64}{200\pi} = 0.007.$$

If, however, it is desired to have the burst occur when α is approximately 60 degrees, for an assumed maximum fragmentation density in that direction, $f^2(60°)$ is about $\frac{1}{2}$ and

$$r^2 = \frac{p^2}{\sin^2\alpha} = \frac{4p^2}{3}.$$

These values make

$$M_0(60°) = 0.0026. \tag{140}$$

Experiments have shown that the loss associated with the dynamic response of shaped amplifiers is about 10 per cent. Thus we reach the final conclusion that a workable fuze must function when

$$M_0 \cong 0.0025. \tag{141}$$

To refine the calculation further would be useless, since the answer is only approximate. Trial fuzes were built to fire when $M_0 \cong 0.0025$ and tested against a mockup target. It was found that this value gave good field results, the final proof of any design.

It will be noted that the reciprocal of the value of M_0 required to fire the fuze is a measure of the overall sensitivity of the device. It is convenient, as an aid to thinking, to specify this value in terms of a special type of test. We imagine the fuze moved toward an infinite perfect reflector at such a speed that the doppler frequency is exactly right for maximum amplifier gain. We also assume the projectile to be so oriented that the direction of maximum radiation is toward the reflector. Under these special conditions

$$M_0 = \frac{\lambda G}{4\pi h}, \tag{142}$$

and the fuze will function at a height h, given by

$$h = \frac{\lambda G}{4\pi M_0}. \tag{143}$$

For the calculation just outlined above this reduces to

$$h_{\text{eff}} = \frac{7.5 \times 1.64}{4\pi \times 0.0025} \cong 400 \text{ ft.}$$

For a quick specification of the overall fuze performance this effective height is quite convenient. This method of specifying the sensitivity of a fuze is called the Michigan sensitivity and was used extensively by Section T, Office of Scientific Research and Development.

Experience resulting from tests against a mockup target as well as against actual targets has shown that fuzes with $h_{\text{eff}} = 400$ ft are quite satisfactory, but that greater sensitivity can be used with increased effectiveness. Values as high as 800 to 1,000 ft have been achieved in later models.

The effective height as defined above should be used only for comparing the effectiveness of fuzes working on a given frequency. As seen from equation (143), h_{eff} is proportional to λ. On the other hand, for an airplane target, M_0 is not proportional to λ but to a first approximation is proportional to $\lambda^{\frac{1}{2}}$. Thus for smaller λ, h_{eff} is reduced while performance against an airborne target is not reduced in proportion (see Section 2.11.3 following).

2.11.3 Effect of λ on Reflection from Aircraft

Equation (134) shows that for all other constants equal

$$M_0 \sim A\lambda. \tag{144}$$

Mott[93] has calculated the values of A for various simple reflectors and finds

Dipole:	$A \sim \lambda^1$.
Sphere:	$A \sim \lambda^0$.
Flat plate:	$A \sim \lambda^{-1}$.

Considering all factors, he recommends as a working average value $A \sim \lambda^{-\frac{1}{2}}$. Equation (144) then becomes

$$M_0 \sim \lambda^{\frac{1}{2}}$$

as an average case and $M_0 \sim \lambda^0$ for the case of a flat sheet like an airplane wing. Our fuze experience indicates that the behavior is more nearly the latter than the former.

2.12 SIGNAL SIMULATION[h]

2.12.1 Properties Required of Simulator

In the preceding sections a description of the impedance signal due to a reflector has been given, and it has been shown that the changes in amplitude and phase of the impedance signal M are duplicated as amplitude and phase changes in dV.

The value of M is a function of position alone and can be represented as a space pattern along the trajectory. This space pattern has been called the M wave. The value of M as a function of time is obtained once the position is known as a function of time. The form of the M wave is not altered by the velocity of approach; the wave is merely traversed at an appropriate rate. This means that it is possible to measure the M wave point by point with static impedance measurements and compute its time variations in any given case from the specified relation between position and time.

[h] Bibliographical references pertinent to this section are 3, 7, 35, 46, 76, 92.

[redacted]

If we are to simulate the working impedance signal, we must devise an arrangement which presents to the fuze circuit an impedance which has the correct amplitude and time dependence. We are not concerned here with a device which attempts to simulate the vibration and stress conditions encountered by the fuze in actual use.

Experience has shown that the r-f part of the fuze system is able to respond to changes of antenna impedance much more rapidly than any encountered by the fuze in practice. This means that the audio-frequency circuit is the part of the fuze that responds to velocity changes. As a result of this division of function, it has been found desirable to test the r-f system and audio system separately in engineering the fuze design. A final test which simultaneously measures the combined performance of the complete system serves as an overall check to insure that there are no undesirable interactions.

A truly faithful simulator must actually reproduce the rotating impedance vector which is characteristic of the interaction with the moving target. However, it will be seen in Section 3.1.7 that the sensitivity of the r-f circuit to reactance changes is usually negligible in comparison with the sensitivity to resistance changes, so that a simulator which reproduces the resistance component of M is adequate for most work. This simplifies the simulator problem greatly but it must always be remembered that an approximation is involved when such a "resistance simulator" is used.

Additional properties that a simulator must possess are those which make its use practical. It must have a sufficient range of operating conditions, it must be reproducible, it must be convenient to use, and it must not introduce complicating disturbances into the fuze circuit.

2.12.2 Field R-F Simulator

There is one convenient method of simulation of the true antenna impedance variation that involves the use of a field setup. It is in fact not a simulator in the true sense of the word, since it reproduces the actual voltages as a function of distance from the target but not on the proper time scale. It is, however, discussed here, since it is one method for presenting the proper antenna variations to the r-f system. We refer to what is commonly called a "pole test."

In making pole test measurements, a fuze is mounted in a mockup of the proper projectile and suspended over a large reflecting screen by ropes attached to tall poles. The height above the reflector is varied, and point by point readings of the voltage dV are recorded. The requirement for proper antenna simulation is automatically fulfilled.

If the readings are taken at a height of several λ, M_0 is quite small, and we can say that

$$dV = M_0 S_0 \sin\left(\frac{-4\pi h}{\lambda}\right), \tag{145}$$

except for a fixed phase shift which has been neglected. If calculated values of M_0 are substituted in this expression, S_0 can be calculated for a given r-f circuit.

In practice it is difficult to obtain the readings at a very large height so that M_0 may be as large as 6 to 10 per cent. It can be shown that the error in S_0 calculated in this manner is about the same size as M_0. Such measurements are accurate enough for most purposes.

There is apt to be a large error in pole test measurements if the reflecting screen is not large enough. When the height of the fuze becomes comparable with the semidiameter of the screen, diffraction effects set in which are of unknown phase and magnitude. Errors as large as 100 per cent have been observed. It is desirable to have the screen diameter at least four times the height of measurement.

2.12.3 Laboratory R-F Simulators

By laboratory r-f simulators we mean those devices which generate impedance changes of a form suitable for making tests of the complete r-f system, but which do not have the amplitude-time dependence necessary for testing a complete fuze system. They fall into two general categories, those which vary the resistance component alone and those which set up the true rotating impedance vector. The

[redacted]

latter, while interesting, do not give enough additional information on present-type fuze circuits to justify their construction. Both types will be discussed briefly. Since the fuze circuits used at the present time have small reactance sensitivity, there has been no need for reactance simulators, and none has been designed. However, as will be pointed out, the reflecting dipole simulator can be used as a reactance simulator if desired.

Resistance Component Simulators (Substitution)

This is the simplest of all tests to make in the laboratory. One merely disconnects the fuze antenna from the circuit and adds a dummy antenna consisting of lumped resistors and condensers, which duplicate the operating point of the r-f system. The resistance is varied by substituting several resistors in succession. A curve of V versus $\ln R_p$ (or $\ln R_s$) is plotted, and the slope of this curve at the operating point is the sensitivity S_p (or S_s).

If desired, the fuze assembly can be placed inside a shield can instead of removing the antenna exciter. Such an arrangement leaves the operating point reactance practically unaltered, and resistors can be substituted directly across the feed point. This latter method is preferable, since any stray coupling between oscillator and antenna is left undisturbed.

Figure 36 shows a typical load curve obtained from such a series of measurements. It is a curve of V versus R_p on a logarithmic scale. From such a curve S_p, which has been defined as $dV/d \ln R_p$, may be found.

Resistance Component Simulators (Dipole Reflectors)

The dipole reflector is not strictly a resistance simulator, since it can be made to perform as a rotating vector simulator, resistance simulator, reactance simulator, or combination simulator.

We may see with the aid of equations (48) and (94) that the reflection from a half-wave dipole oriented so that $f_3^2(\theta_{31},\phi_{31}) = 1$, is given by

$$M = 1.64\left(\frac{\lambda}{2\pi r}\right)^2 \frac{R_{s3}}{Z_{33}} G_1 f_1^2(\theta_{13},\phi_{13}) \cos^2 \tau e^{j[(-4\pi r/\lambda)+\delta]}. \tag{146}$$

We see that M can be changed by changing r, Z_{33}, $f_1^2(\theta_{13},\phi_{13})$, and τ. All these changes have been utilized at one time or another. The dipole is adjusted so that

$$Z_{33} = (R_{s3} + Z_L), \tag{147}$$

where Z_L is the external impedance connected to the feed terminals of the dipole. If we short the terminals, $Z_L = 0$, and Z_{33} reduces to R_{s3}.

Wand. A wand consists of a length of wire cut to resonant length. In effect $Z_L = 0$, since the terminals are shorted. It can be used in two ways. First, it can be oriented so that $\tau = 0$ and moved toward or away from the fuze antenna, thus varying r. When so used the signal presented to the fuze is truly the rotating vector, and the changes dV can be recorded as the wand is moved.

Second, it can be so located that M is purely resistive. τ may then be varied by twisting the dipole in a plane perpendicular to r, thus varying the effective resistance. If desired, the dipole can be attached to a motor so that $\tau = \omega t$. Then an audio signal will be developed which varies as $\cos^2 \omega t$.

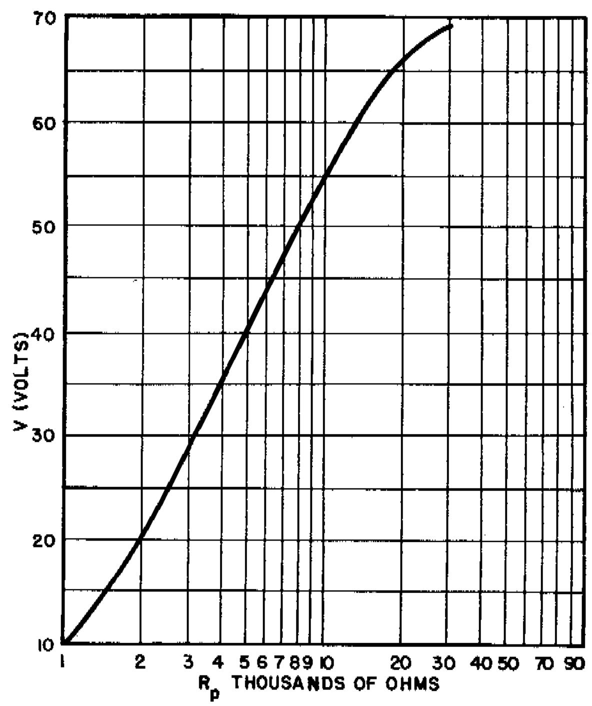

FIGURE 36. Typical loading curve.

If reactance simulation is required, r may be adjusted so that M is purely reactive and the rotation gives a reactance variation instead of a resistance variation.

Modulated Dipole. The term Z_L can be varied by connecting a variable impedance to the terminals of the dipole. The variable impedance can be provided by a rotating condenser, commutator, flashing thyratron, or any other convenient form of variable r-f impedance. Unless the variable impedance can be made purely resistive or purely reactive, the resulting M becomes quite complicated because time-varying phase shifts arising from changes in Z_L are included in the reflector.

When dipole simulators are used in the laboratory, stray reflections set up complicated standing waves in the room, and only qualitative answers are obtained. A change of position of the dipole with respect to the fuze varies $f^2(\theta,\phi)$ and gives crude information about the directivity of the fuze.

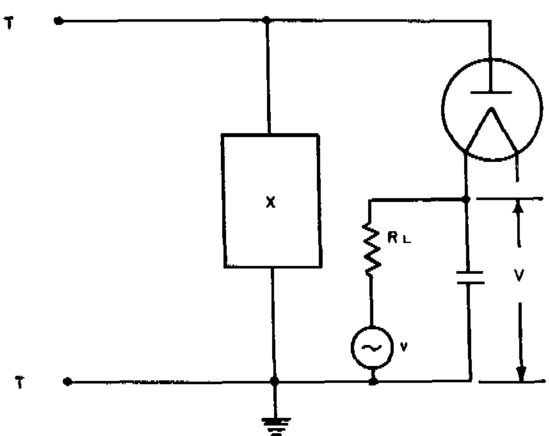

FIGURE 37. Basic circuit for diode simulator.

Such devices are useful for quick checks to see if fuze circuits are "live" and have approximately the desired sensitivity. Because of the $(\lambda/r)^2$ factor in the reflection the device can not be used effectively at a large distance from the fuze and hence cannot be used well for measuring directivity patterns.

Resistance Component Simulators (Diode)

The a-c input resistance of a linear diode voltmeter is a function of the d-c resistance and d-c voltage in its load circuit. The fundamental circuit for a diode simulator is shown in Figure 37.

Terminals TT are connected to the antenna terminals of the fuze circuit. The reactance X represents lumped reactance (including a d-c return, if necessary) to make the input reactance of the device simulate the operating point reactance of the fuze antenna.

By varying v and R_L the apparent r-f resistance R between terminals TT can be controlled. In practice R_L is adjusted to give the value of R at the operating point when $v = 0$. The term v is then varied at an audio-frequency rate to introduce small periodic variations in R.

If the diode is working in its linear region so that a d-c voltmeter indicates a voltage V across R_L of several volts, the simple diode theory works quite well. Let R_p be the dynamic resistance of the diode and θ the semiangle of flow when $v = 0$. If $v/V << 1$ it can be shown that

$$\frac{dR}{R} = \frac{vR}{VR_L}(2\cos^2\theta) = \frac{v}{V}\rho, \qquad (148)$$

where θ is determined by

$$\frac{R}{R_p} = \frac{\pi}{\theta - \cos\theta\sin\theta}, \qquad (149)$$

and subsequently R_L is determined by

$$\frac{R_p}{R_L} = \frac{1}{\pi}(\tan\theta - \theta). \qquad (150)$$

Figure 38 shows the appropriate values of R_L to give the desired value of R when R_p is known, and the value of ρ, the correction factor that must be applied to v/V to give dR/R.

It is not wise to use values of R/R_p less than 10. If lower values of R are needed, a fixed resistance can be shunted across the circuit, with X and the ratio of v/V adjusted accordingly to make the overall dR/R have the desired value.

The diode simulator need not be connected directly to the antenna terminals but may be capacitatively coupled, if appropriate calculations are made and provided the diode is operated in its linear region.

In laboratory work it is advantageous to calibrate the simulator directly by attaching it to a stable fuze circuit which has a known load curve. The desired operating point is selected

[redacted]

and the output of the fuze circuit measured as a function of v/V. From the measured output and the known load curve the effective dR/R for the simulator can be calculated directly with no detailed knowledge of the diode. The theory above serves as a useful guide in selecting proper diodes and in indicating the range of usefulness of a given simulator.

The *diode simulator* has a considerable advantage over thermistor-type simulators

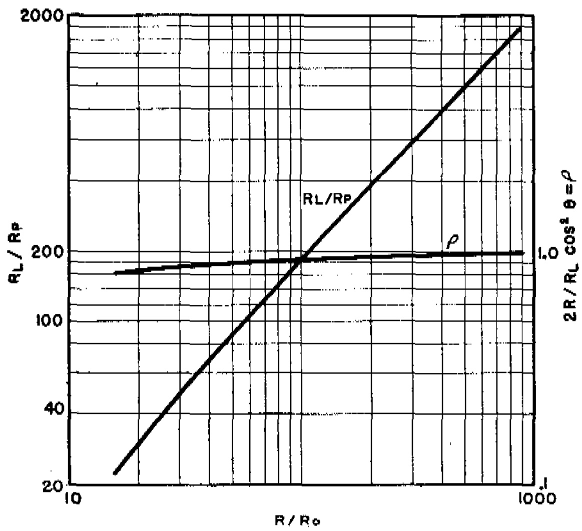

FIGURE 38. R_L/R_p and ρ as functions of R/R_p.

because there is no delay in response to the applied audio voltage. Tests have shown that the device will follow frequencies far in excess of any required in fuze testing.

Resistance Component Simulators (Thermistors)

The effective resistance of an r-f circuit can be controlled by incorporating a thermistor element somewhere in the network. The temperature of the thermistor can be varied at an audio rate by passing audio-frequency current through it. This results in a variation of the effective resistance of the r-f circuit at an audio-frequency rate.

Typical thermistors that have been used are small flashlight bulbs and Littel fuzes. Because of the thermal lag of such devices the upper audio frequency is quite limited, and each device requires calibration against a standard fuze circuit of known stable performance.

A detailed description of a thermistor simulator and its calibration will be found in an NDRC report,[3] which shows the general procedure for calibration of any resistance simulator.

Resistance Component Simulators (Triode)

The effective resistance of an r-f circuit can be controlled within limits by loading it with a triode so arranged that the dynamic plate resistance of the triode is used as an r-f resistance. The value of the dynamic plate resistance can be changed by changing the grid to cathode potential of the triode. The changes in plate resistance respond to changes in grid voltage at frequencies far greater than any needed in fuze testing. Hence this device compares favorably with the diode simulator. Calibration is necessary, and in general the circuit arrangement is more complicated than for an equivalent diode simulator. The details of a typical triode simulator developed by the Philco Corporation are shown in their final report.[76]

Rotating Vector Simulators

There has been little need for true rotating vector simulators aside from the pole test, which serves as a final check on any fuze circuit. In some special phases of fuze work, however, a rotating vector simulator is of interest.

Several schemes have been proposed and two put into practice. One of these is a side-band type by Airborne Instruments Laboratory for use in their countermeasure studies; another has been designed by Westinghouse for testing a pulse type of fuze.

The first type receives a carrier from the fuze, adds two side bands at simulated doppler frequency and cancels out the carrier plus the lower side band. The upper side band is amplified and reradiated to form a true rotating vector simulator when mixed in the fuze circuit. The details will be found in an NDRC report.[92]

The second type uses a transmission line with two resistance simulators located at points separated by $(\lambda/8)$. The audio drive on one simulator is 90 degrees ahead of that on the other. The resultant effect of the two is a rotating impedance vector at the input to the line, when

the load presented by each simulator is properly adjusted.

2.12.4 Laboratory Audio Simulator

As has already been pointed out the voltage wave into the amplifier is of the form

$$dV = MS, \tag{151}$$

and S is essentially a constant of the r-f system. The control of burst and discrimination against noise are performed in the amplifier control section of the fuze. In testing this part of the system, it is not necessary to include the r-f elements, provided an audio voltage wave proportional to M can be generated. If actual wave forms of M were sufficiently simple, laboratory sine wave oscillators could be used for all audio circuit tests.

The rate of change of instantaneous frequency and amplitude of the M wave for an airborne target are so large that it is extremely tedious to predict amplifier performance on the basis of its steady-state response to sine waves of various frequencies or on the basis of its transient response to a unit pulse.

It has been found very convenient to circumvent these difficulties by constructing an audio-frequency simulator which generates a wave which is in detail like the wave measured in the fly-by tests described in Section 2.11.3.

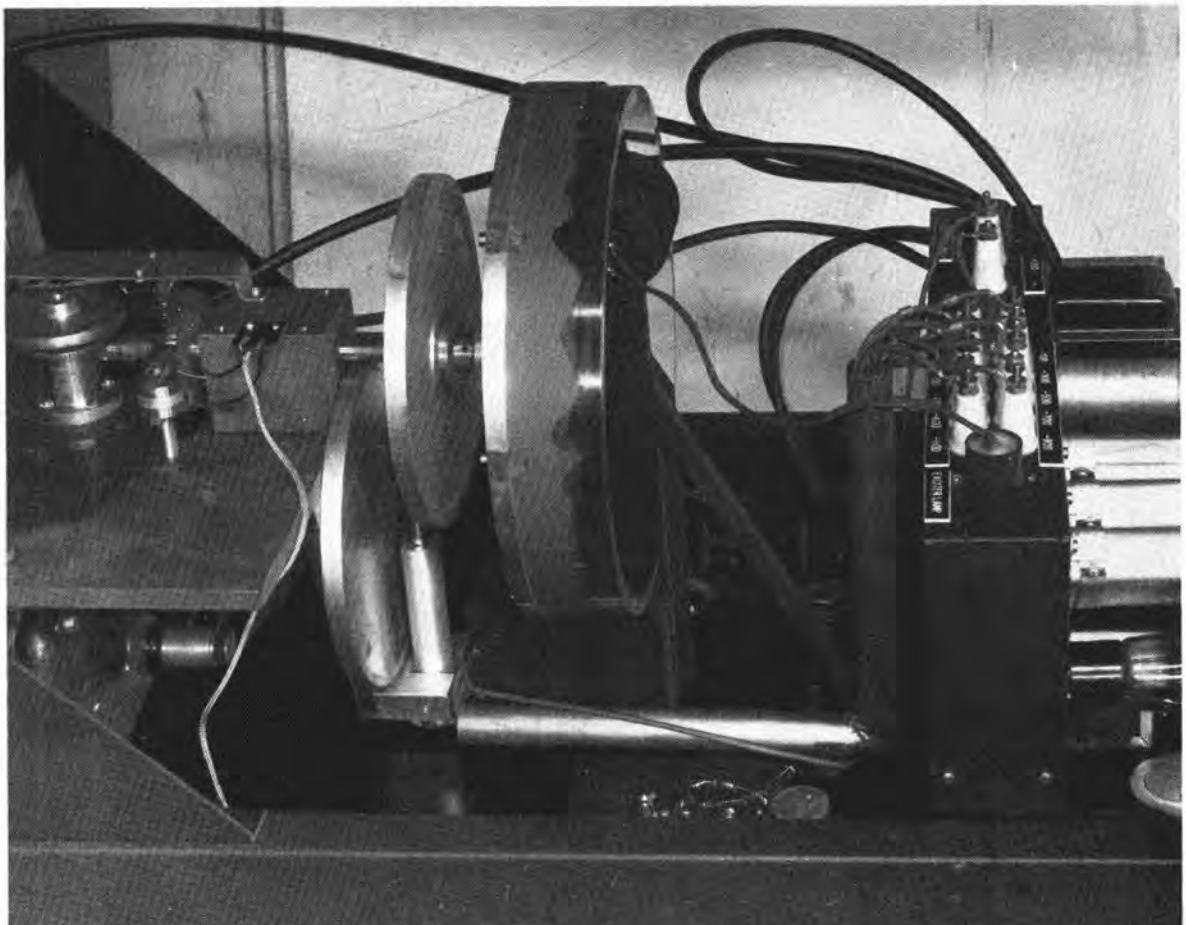

FIGURE 39. Audio-frequency M-wave simulator; view of drum and associated equipment.

In principle the device is quite simple. The desired wave form is cut on an opaque paper

tape and wrapped around a transparent cylinder. A light source is placed inside the drum. It illuminates a tiny transverse strip of the tape by means of a slit. A photocell on the outside of the drum measures the light passed by the tape. When the drum is rotated by a motor drive, the M wave of voltage is generated.

Since the form of the M wave does not depend upon the speed of the projectile, the same

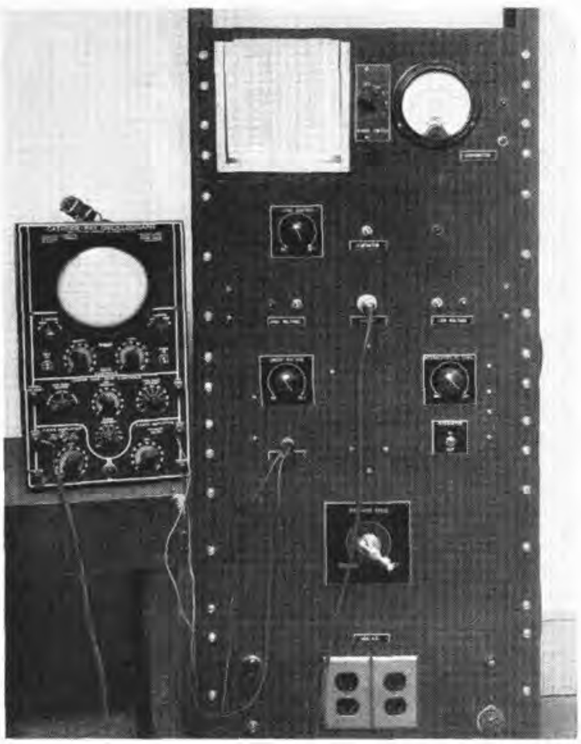

FIGURE 40. Audio-frequency M-wave simulator; view of control panel.

wave can be used for all projectile velocities. Thus the speed of rotation of the drum corresponds to projectile velocity, and a whole range of interaction velocities can be simulated with a single adjustment.

If an oscilloscope sweep is synchronized with the drum rotation, it becomes a simple matter to investigate delay in circuit response. By incorporating several channels, noise of typical forms can be superimposed on the M-wave signal to demonstrate the discriminating properties of audio control circuits.

Figures 39, 40, and 41 show photographs of a typical audio simulator, and oscillograms obtained with it.

The audio simulator is used also in studies of the ground-approach M wave. Although this wave form is not so complicated as that from an airborne target, the rate of rise of amplitude

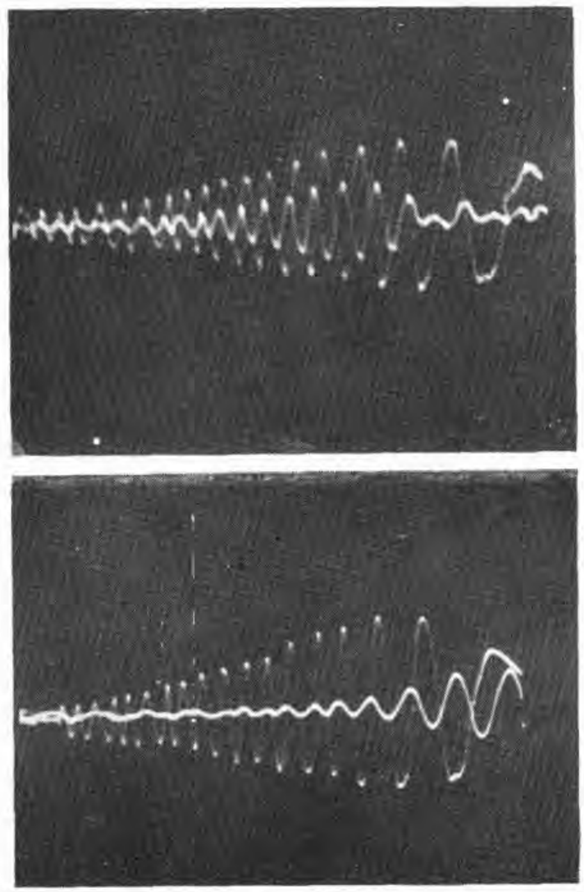

FIGURE 41. Simulated M wave obtained with audio-frequency M-wave simulator, with superposed response of amplifier to simulated M wave. In each photograph the curve of larger amplitude represents the M wave. The superposed amplifier response is scaled down. In the upper photograph an amplifier peaking at 100 cps was used; in the lower photograph the amplifier peak was 50 cps.

is large enough to make dynamic studies of the amplifier necessary. These are performed more easily on the audio simulator than by calculation.

The audio simulator has proved itself to be a worth-while research tool and may be of considerable use for other laboratory work.

2.12.5 Overall Signal Simulator

In case it is necessary to simulate at the antenna terminals the complete variation of impedance, a combination of the audio simulator with the resistance simulator of the diode or triode can be used. The voltage from the audio simulator is used to drive the r-f resistance simulator. The result is a wave which presents the correct variation of radiation resistance to the fuze circuit. Reactance changes will not be included, but they are not normally needed.

2.13 ANTENNA NOISE

2.13.1 Introduction

We have seen in equation (44), reproduced here for convenience,[10, 42-45] that the presence of a reflecting body changes the input impedance of the fuze antenna, thus

$$Z_1 = Z_{11} - Z_r. \tag{44}$$

We in effect altered this equation to read

$$Z_1 = Z_{11} - MR_s = Z_{11}\left(1 - \frac{MR_s}{Z_{11}}\right), \tag{152}$$

and tacitly assumed that Z_{11} is constant so that the only changes in Z_1 are those produced by M. We have also seen that expected values of M_0 are very small (~ 0.0025 for the airborne-target case) and that fuzes are designed to work on these small changes when they have a proper time dependence.

Now a fractional change in Z_{11} will be just as effective in actuating the fuze as the whole of M, if it has the proper time dependence. Such a change is indistinguishable from the expected signal, and the fuze will function if these changes in Z_{11} occur.

There are two physical differences between the M signal and a variation of Z_{11}. These are (1) the time delay associated with the time of flight of the radiation to the target and back and (2) the fact that the M signal is a returning wave instead of an outgoing wave.

Up to the present time no practical schemes have been evolved for making any differentiation. Such schemes will no doubt be developed, but the fuzes with which this report is concerned cannot make the distinction. The conventional radar pulse-time system makes the necessary distinction but has not yet been developed in a form suitable for small fuzes. Hence a variation of Z_{11} gives rise to a signal of the same form as the M signal.

Unfortunately circumstances arise wherein Z_{11} is not constant, and we are forced either to rely upon the difference in time variation to discriminate between M and variations in Z_{11} by means of the audio control system or to go to severe lengths to hold Z_{11} adequately constant. There are two sources of variation in Z_{11}. These are (1) geometric deformations of the antenna structure associated with vibration, and (2) erratic additions to the antenna system arising from propellant flames associated with the projectile itself. The latter source of trouble is associated only with self-propelled projectiles such as rockets or guided missiles.

It may be mentioned that the problem of thermal noise never arises, since the signal levels used are always much higher than the thermal noise level.

Signals originating in radiators other than the fuze are considered interference, and the susceptibility of fuzes to these signals is not primarily an antenna problem but rather an internal circuit problem. The antenna plays a small part by virtue of its reception pattern, effective length, and polarization. These properties have been discussed in preceding sections and need not be considered further.

The whole interference problem is intimately related to the problem of countermeasures for the fuzes and is therefore not treated in detail here. We now turn attention to the antenna noise as defined above.

2.13.2 Antenna Noise Resulting from Geometric Deformations

The normal dimensional deformations associated with vibration in projectiles are so small that they can be neglected. The real trouble arises when the vibration varies the contact resistance (or impedance) between parts of the projectile. This may occur between parts of a

welded-fin structure on bombs, at the point where the fins are attached either on bombs or rockets, at the point where the fuze is attached to the projectile, and at the point where the power vane is attached to the fuze.

The obvious solution to the whole problem is to make all joints so tight electrically that the variations do not matter. Usually it is possible to achieve the required tightness provided (a) the fins are made properly, and (b) the assembly is tight when the projectile is used. It is difficult, if not impossible, to simulate in the laboratory vibration conditions like those set

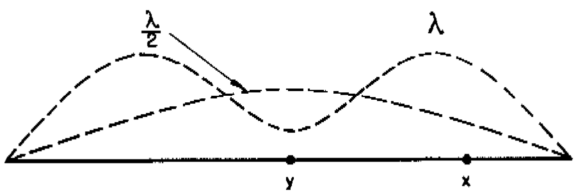

FIGURE 42. Two possible current distributions on fuze antenna.

up in the actual projectile. Thus the only experimental method of determining when the desired degree of tightness has been achieved is to make field tests with real projectiles carrying fuzes known to be internally quiet. Such experiments are made with each type of projectile to be used, for "proving-in" purposes.

The antenna noise generated by the rotating power vane cannot be removed by tightening the system. It can be reduced by putting an electric shield around the propeller, as in the case of the ring-type antenna, or by using a rotating system whose speed is so high that the noise frequency is higher than the expected doppler frequency. The audio control system can then discriminate between the doppler frequency signal and the antenna noise. This latter device is used in both bar- and ring-type fuzes. The erratic noise set up in the nose bearings is reduced to an acceptable level by keeping the amount of metal in the rotating system exposed to r-f fields very small.

When tactical conditions and engineering design considerations permit, the noise level can be reduced by an appropriate choice of carrier frequency. To see this consider the schematic antenna system shown in Figure 42. The different standing waves of current are shown by the dotted lines. The single-lobe pattern corresponds to a frequency such that the antenna is about $(\lambda/2)$ long. The double-lobed pattern is that for a frequency such that the antenna is nearly λ long. Suppose that the contact resistance varies at point x. The current through x is larger for the λ wave than for the $(\lambda/2)$ wave. Hence the power absorbed at x varies more for a given variation in x when the λ pattern is used than when the $(\lambda/2)$ pattern is used. Power absorption appears as variations in Z_{11} and hence appears as a spurious signal.

If the noise point happened to be at y, the λ pattern would be better. Usually the fuze joint is near one end and the fin joint near the other, and it is not possible to get a current pattern which places nodes at these points. Furthermore, fat antennas do not have marked nodes except at the ends. For this reason it is generally better to use a low carrier frequency to suppress vibration noise.

This argument has been verified in the field in the case of longitudinally excited 500-lb bombs.

2.13.3 Antenna Noise Resulting from Propellant Flames

Rockets are particularly subject to this type of noise, since they carry a long flame behind them for a considerable portion of their flight. It is possible to delay the arming of the fuze until the propulsion blast is over without impairing the effective use of present-day rockets too greatly. However, the trend is toward longer burning rockets and the flame is sure to become a serious problem. Furthermore, there is more to the problem than first appears. When the burning is over, the flame does not go completely out and remain so. Scraps of unburned propellant left in the hot motor reignite and give small "chuffs" of flame which do not disturb the motion of the rocket but which do disturb the behavior of the antenna. These chuffs of flame have been found to occur erratically many seconds after the main burning

[redacted]

of the propellant has ceased. They create large enough changes in Z_{11} to cause the fuze to function before it reaches its intended target. The problem of afterburning, as the phenomenon of the chuffs has been called, has been a serious one in the case of present-day rockets, and considerable effort has been expended in seeking a solution of the problem.

The attack on the problem has taken two main lines. These are as follows:

1. A study of the electric properties of the flames to see how circuits can be designed to suppress the response. Such electric properties are within the scope of this chapter.

2. A study of the means for eliminating the afterburning problem by stopping the afterburning. This phase of the attack is treated in another chapter, since it is not an antenna problem.

The electrical effects of the flame result in the production of a spurious signal which can be distinguished from the expected M signal only by its different time variation. It has been a simple matter to show that the flame does actually produce large spurious signals. A rocket carrying a fuze was mounted on an insulating stand and connected through insulating hose to supplies of gas and air. By this means flames of any desired size could be produced at the end of the projectile. Recording instruments were connected to the fuze in such a manner as to leave its radiating properties essentially undisturbed.

Arrangements were also incorporated so that the flames could be started or stopped quickly. The sudden change gives rise to time-dependent effects which can be easily separated from the steady-state r-f conditions in the absence of the flame. Several interesting properties of the flames were immediately evident.

1. The yellow sooty flames from pure illuminating gas had no measurable effect.

2. The clear blue flame from a mixture of gas and air had no effect.

3. When arrangements were made to spray NaCl, or KCl solution or powdered salt into the flame, a large response was observed immediately. The changes were five to ten times those needed to trigger the fuze normally.

4. The effective flames were not in contact with the fuze, being separated from it by an inch or more of nonburning nonionized gas.

5. The magnitude of the effect could be changed by changing the concentration of the ionizing substance injected into the flame.

6. The magnitude of the effect could be changed by changing the flame length.

Figure 43 shows a typical curve of signal versus flame length. The ordinate is expressed in terms of the value of M_0 that would be required to give the same signal. The arrow near the base at 0.0025 represents the working value of M_0 for which the fuze was designed to fire when the proper signal is approached.

It was next necessary to demonstrate that the rocket propellant actually carried enough

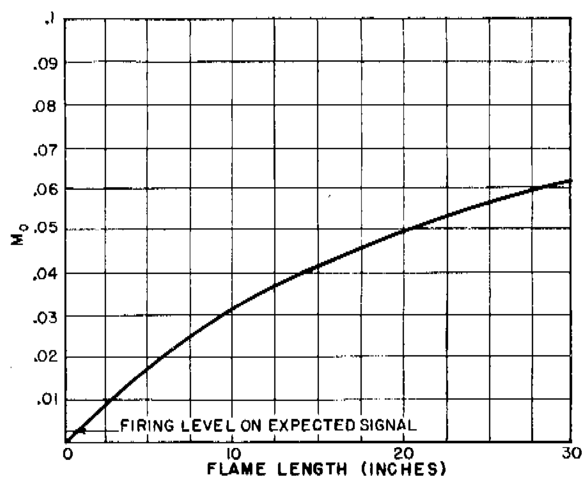

FIGURE 43. Signal produced by flame, as function of flame length.

ionization to do what the flames did. To check this a rocket was supported on a strong insulating support, and voltage changes measured while the main burning was going on. Voltages larger than in the above described experiment but of the same order of magnitude were observed. The effect of afterburning was checked by putting small amounts of propellant near the nozzle of the motor and igniting them with a hot wire. The signals from the lower-temperature burning were still of the same order of magnitude.

These tests leave no room for doubt about the signal-producing properties of a flame. Field

[redacted]

tests have shown that such flames do exist and that they are associated with fuze functions.

Studies of circuit behavior were undertaken to see if other carrier frequencies might be useful. Reasonable changes which could be readily incorporated into the fuze design were investigated. None of these changes eliminated the effect of the flames.

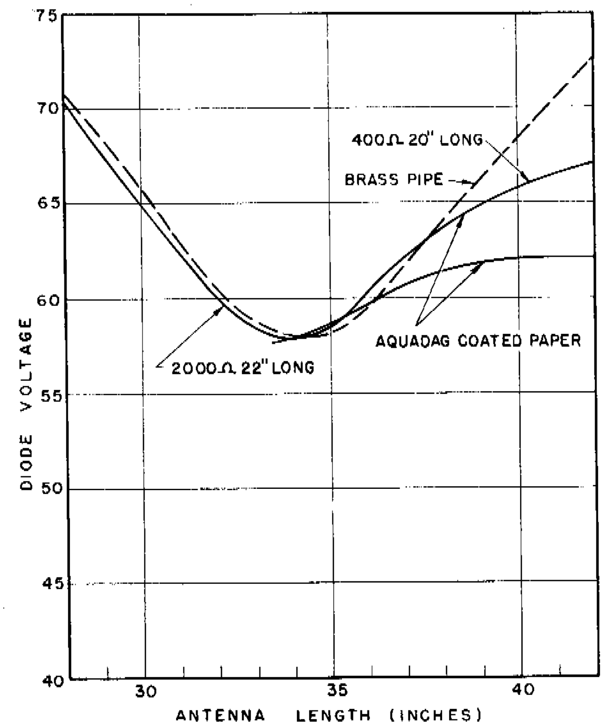

FIGURE 44. Diode voltage versus antenna length.

Figure 44 shows curves of the d-c voltage output (diode voltage in this case), from the r-f section as a function of the length of the projectile-antenna. Time-dependent changes in this voltage represent the dV set up by the M wave. In effect the curve may be considered to be a plot of R_p although it is not exactly proportional to it.

To get the curves a piece of brass pipe was used to simulate the rocket. The upper dotted curve in this figure shows the voltage as a function of the length of brass pipe. The length of 33½ in. corresponds to the length of the rocket for which the fuze was designed.

The lower two curves show the response when the length in excess of 33½ in. consisted of a paper tube coated with Aquadag. The coating was found to have a d-c resistance of 20 ohms per in. for the upper curve and about 100 ohms per in. for the lower curve. These curves indicate the effect of an extension to the antenna which is not a very good conductor. That is, it simulates more nearly the conditions of the conducting flame. We see that the lengthening of the antenna gives voltages which are very large compared with the 30-mv signal required to fire a fuze. They are larger than those observed from the flames. This was thought to be due partly to the air gap between the flame and the antenna.

To show that the size of the gap makes a considerable difference in the effect of the extension, two cases of metal extensions were investigated. Figure 45 shows the results. A 12-in. length of pipe changes the voltage about 10 v when connected directly to the end of the antenna. When pipe and antenna are separated to leave a ½-in. air gap the effect is reduced to about 1 v, the order of magnitude of the measured effect from the flames. If a resonant length of pipe is used for an extension, the effect is not so sensitive to separation. Still there is a

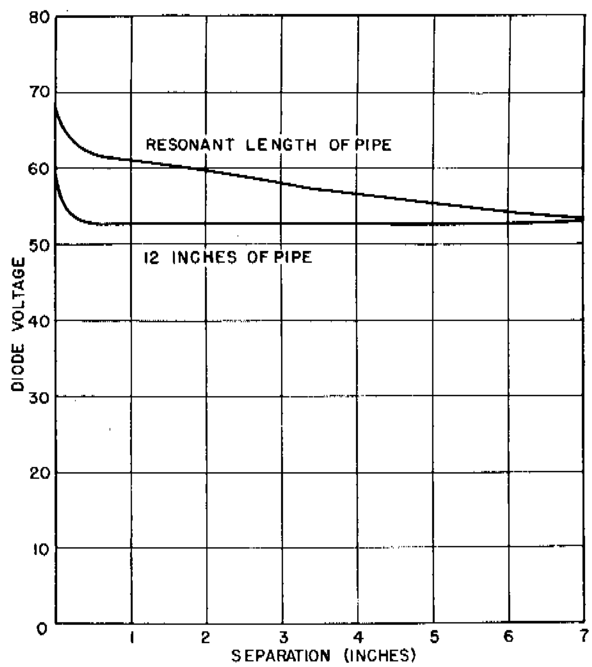

FIGURE 45. Effect upon diode voltage of metal extensions to antenna.

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marked reduction for an inch separation, which is about the space observed between the flame and the projectile. There is, of course, no way of knowing what the length of a particular flame may be from any particular projectile. All we can say from these experiments is that the effect of flames is consistent with a theory of antenna length changes.

We see from the figures that it is possible for a change in antenna length either to increase or to decrease the voltage by selecting the frequency or length properly. In particular, for

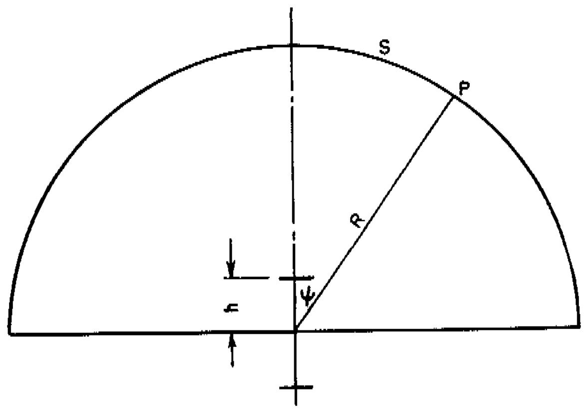


FIGURE 46. Horizontal differential antenna with its image.

one assigned length of extension, there is a frequency for which the voltage change due to the presence of the extension will be zero.

In the course of field tests on the afterburning problem, fuzes, operating above and below the resonant frequency, were tried to see if the effect of the flame could be reduced. No improvement resulted, presumably because (1) the flame lengths were too variable, or (2) the transient setup by its change of length or position was too great.

The discussion of the response to flames has so far been concerned with the magnitude of the effect. There remains the problem of its time dependence. If the changes of Z_{11} set up by the afterburning flame have the same time dependence as the expected signal, no internal circuit can discriminate against it. (This assumes the use of a load-sensitive r-f system.)

To date it has been impossible to learn much about the wave form of the afterburning signal. Static measurements leave out the large effects of the airstream on the flame behavior and hence give only crude qualitative answers.

Some investigations have been made to see if a change in the frequency response of the audio-frequency control circuit would reduce the response to afterburning. No significant results were observed. This probably means that the actual afterburning wave form is so erratic that it has sizable components in the pass band of an otherwise acceptable control circuit.

Real improvement has, however, been made in reducing the afterburning effect by changing the design of the propellant or the motor or both.[10] These are temporary expedients, since it is unwise to have the fuze properties dictate propellant and motor design.

There are definite lines of attack which indicate that the response to afterburning and even main burning may be reduced to a negligible value by changing the basic design of the fuze. However, a discussion of such changes is beyond the scope of this volume.

2.14 EVALUATION OF C

This section[23,24] and the following contain additional material supplementing some of the discussions in the preceding section.

In Section 2.4 two relations were derived which are here repeated for convenience.

$$C = \frac{l}{\sqrt{(Z_0 R_s G/4\pi)}\, f(\theta,\phi)} \tag{40}$$

$$Z_{13} = \frac{CZ_0}{4\pi r}\sqrt{R_{s1}R_{s3}G_1G_3}\, f_1(\theta_{13},\phi_{13})\, f_3(\theta_{31},\phi_{31})\cdot (\cos\tau) j e^{j(-2\pi r/\lambda)}. \tag{42}$$

It has been shown that C is a constant for all antennas. The evaluation of C allows the completion of the general equation (42) for the mutual impedance between any two antennas (only radiation fields considered).

Since C is a constant, we are justified in choosing the simplest possible antenna in the evaluation of C. The antenna chosen is the infinitesimal or differential antenna. For such an antenna, $f(\theta,\phi) = \sin\theta$ and $G = 3/2$. The current, whose absolute value will be called I_0,

is constant over the infinitesimal length of the antenna. The power W radiated is

$$W = \frac{I_0^2 R_s}{2}. \tag{153}$$

Any change ΔR_s in the radiation resistance is accompanied by a change ΔW in the power radiated, given by

$$\Delta W = \frac{I_0^2 \Delta R_s}{2}. \tag{154}$$

The above expression is based on the assumption that the current remains constant.

These relations will be used in evaluating C. We shall obtain the mutual impedance between an infinitesimal antenna and its image in the following manner. First we shall compute the additional power ΔW, which the antenna has to radiate to maintain its current I_0 constant in the presence of the image. Then, utilizing equation (154), we shall obtain the resistance component of the mutual impedance. Finally, with the aid of equation (42) C will be found.

Consider the differential antenna to be placed horizontally at a height h above an infinite perfectly conducting horizontal ground (Figure 46). The antenna and its image, to be called respectively No. 1 and No. 2, form a system of two interacting antennas. For this system $f_1(\theta_{12},\phi_{12}) = f_2(\theta_{21},\phi_{21}) = 1$, and $\cos \tau = 1$.

We now have to compute the additional power radiated by the antenna to maintain its free-space current I_0 in the presence of the ground or image. At this point one advantage of using the infinitesimal antenna in this calculation may be mentioned. It is only for such an antenna that we can be sure that the free-space current distribution can be maintained in the presence of the ground.

To find ΔW we can integrate the Poynting vector over a sphere S of large radius. This gives us the total power; subtracting the free-space power W_0, we obtain ΔW.

The fields along the surface of the sphere are due to contributions from the real antenna and its image. In general, some of the radiation from the image (antenna No. 2) is scattered by the real antenna, No. 1. The effect of No. 2 over the surface S is the sum of radiation from No. 2 plus scattering from No. 1. By holding the current I_0 in No. 1 constant in the presence of No. 2, we in effect cancel out the scattered wave from No. 1, since the scattered wave results from an additional current in No. 1. Thus we need consider only the direct contributions from No. 1 and No. 2. At any point P on the hemisphere S, whose radius is R (Figure 46), the instantaneous electric field due to No. 1 is

$$E_1 = \frac{I_0 k}{R} \sin\theta\, e^{j[\omega t - \beta(R - h\cos\psi)]}. \tag{155}$$

The field due to No. 2 is

$$E_2 = \frac{-I_0 k}{R} \sin\theta\, e^{j[\omega t - \beta(R + h\cos\psi)]}. \tag{156}$$

In equations (155) and (156)

$$k = \sqrt{\frac{Z_0 R_s G}{4\pi}},$$

ψ = the angle which the radius vector $\mathbf{R}$ makes with the vertical (Figure 46).

$$\beta = 2\pi/\lambda.$$

The other symbols have been previously defined. In equations (155) and (156) the induction and quasi-static fields have been ignored, since they do not contribute to the power radiated. Adding, we have

$$\begin{aligned} E &= E_1 + E_2 \\ &= \frac{I_0 k}{R} \sin\theta\, e^{j(\omega t - \beta R)} \quad [e^{j\beta h\cos\psi} - e^{-j\beta h\cos\psi}]. \end{aligned} \tag{157}$$

To find the total power W, we have to integrate $|E|^2/Z_0$ over the hemisphere. The details of the integration will be omitted. The result is

$$W = \frac{4\pi I_0^2 k^2}{3Z_0} + \frac{\pi I_0^2 k^2}{Z_0} \cdot \left[\frac{-1}{\beta h}\sin 2\beta h - \frac{1}{2(\beta h)^2}\cos 2\beta h + \frac{1}{4(\beta h)^3}\sin 2\beta h\right]. \tag{158}$$

The free-space power W_0 is

$$W_0 = \frac{4\pi I_0^2 k^2}{3Z_0}. \tag{159}$$

Therefore,

$$\frac{W - W_0}{W_0} = \frac{\Delta W}{W_0} = \frac{\Delta R_s}{R_s} = \frac{3}{4}\left[\frac{-1}{\beta h}\sin 2\beta h - \frac{1}{2(\beta h)^2}\cos 2\beta h + \frac{1}{4(\beta h)^3}\sin 2\beta h\right]. \tag{160}$$

It will be noted that as h approaches zero $(\Delta R_s/R_s)$ approaches -1, showing that the antenna does not radiate when on the ground, as is known.

If h be selected large enough so that the inverse square and cube terms in h may be neglected, we have

$$\frac{\Delta R_s}{R_s} = -\frac{3\lambda}{8\pi h}\sin\frac{4\pi h}{\lambda}. \qquad (161)$$

Thus we see that under such conditions the resistive component of the reflected impedance is proportional to R_s and varies harmonically with the separation between antennas (results obtained previously by other means). With the aid of equation (42), it is now seen that

$$\frac{CZ_0}{8\pi h} R_s G = \frac{3\lambda}{8\pi h} R_s. \qquad (162)$$

Since $G = 3/2$, we obtain

$$C = \frac{2\lambda}{Z_0}. \qquad (163)$$

It is also interesting to note that this calculation, which is based upon radiation fields alone, shows the contribution to the radiation resistance arising from the interaction between inverse square and inverse cube fields of antenna and image, which of themselves do not radiate power on the average.[23, 24] While this argument holds for the infinitesimal dipole, it does not hold for large antennas, since the proximity to ground may alter the current distribution on the finite antenna. The argument gives correct results for distances large compared to the dimensions of the antenna.

2.15 PATTERN ERRORS DUE TO GROUND REFLECTION

The experimental setup for measuring directivity patterns has been described in Section 2.8. There are certain errors inherent in these measurements because of the reflection from the ground; it is the purpose of this section to discuss these errors.

Referring to the field setup described in Section 2.8, the resultant field strength at the receiving antenna is composed of two parts: (1) a direct ray from the transmitting antenna, and (2) a reflected ray from the ground. It is convenient in computing these effects to treat the radiating system as consisting of the transmitting antenna and its image.

In Figure 47 the coordinate system is a rectangular xyz system with origin at the center of the image antenna; the image antenna lies along the y-axis. The real antenna is situated at a height $z = 2h$ above the xy plane. The receiving dipole is at a distance a from the transmitter and is always tangent to a circle of radius a whose center is the transmitter. The angle θ is the angle of azimuth and represents the angle of rotation of the antenna in the field setup. The angle of elevation of the

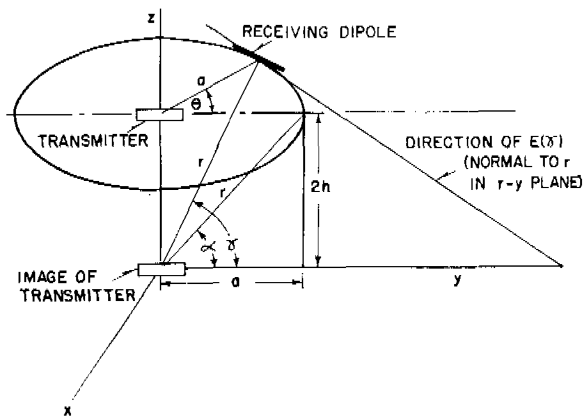


FIGURE 47. Coordinate system used for computing reflected field in radiation pattern setup.

dipole with respect to the image antenna is α. The distance from the image to the dipole is r. It is seen that $\cos\alpha = (a/r)$.

The ray from the real antenna to the dipole makes the angle θ with the axis of the antenna and is perpendicular to the dipole. The electric vector associated with this ray is parallel to the dipole. The ray from the image to the dipole is also perpendicular to the dipole and makes an angle γ with the image. The term γ, as shown in the diagram, is given by the relation

$$\cos\gamma = \frac{a\cos\theta}{r} = \cos\alpha\cos\theta. \qquad (164)$$

From the relation of equation (164), γ is plotted versus θ (Figure 48) for $\alpha = 15$ degrees, which represents the actual situation for the measurement of a large number of patterns. Now the electric vector associated with the reflected ray

[redacted]

is not in general parallel to the dipole. The component E_r of the electric vector of the reflected ray, parallel to the dipole is given by

$$E_r = E(\gamma) \cos \tau. \tag{165}$$

In the above equation $E(\gamma)$ represents the radiation field in the direction γ from the image antenna. The term τ is the angle between the direction of $E(\gamma)$ and the dipole. The term $E(\gamma)$ is in the plane determined by r and the y axis, and is perpendicular to r.

Then τ may be evaluated as follows: The direction cosines l, m, and n, of the dipole are seen from Figure 47 to be

$$l = \cos \theta,$$
$$m = \sin \theta,$$
$$n = 0.$$

For the direction of $E(\gamma)$ we obtain the corresponding values:

$$l' = \frac{a}{r}\frac{\sin \theta}{\tan \gamma} = \frac{\cos \alpha \sin \theta}{\tan \gamma},$$

$$m' = \sin \gamma.$$

Then

$$\cos \tau = \frac{\cos \theta \cos \alpha \sin \theta}{\tan \gamma} + \sin \theta \sin \gamma,$$
$$= \frac{\cos \gamma \sin \theta}{\tan \gamma} + \sin \theta \sin \gamma,$$
$$= \frac{\sin \theta}{\sin \gamma}.$$

Thus we have

$$E_r = E(\gamma)\frac{\sin \theta}{\sin \gamma}. \tag{166}$$

The correction factor $(\sin \theta/\sin \gamma) = \cos \tau$ is plotted versus θ in Figure 48 for $\gamma = 15$ degrees.

The total field strength parallel to the receiver is the resultant of E_r and the field associated with the direct ray, denoted by E_d. This resultant we shall call E_t.

We may write E_d and E_r as follows:

$$E_d = \frac{Af(\theta)}{a} e^{j[\omega t - \beta a - \epsilon(\theta)]}, \tag{167}$$

$$E_r = \frac{nAf(\gamma) \sin \theta}{r \sin \gamma} e^{j(\omega t - \beta r - \epsilon(\gamma) - \Phi)}. \tag{168}$$

Also

$$E_t = E_d + E_r. \tag{169}$$

In the above equations, A is a constant of proportionality, and $f(\theta)$ and $f(\gamma)$ are the magnitudes in the true radiation pattern for θ and γ; the terms $\epsilon(\theta)$ and $\epsilon(\gamma)$ represent the phase of the radiation field for θ and γ; a and r are the distances from the receiving dipole to the fuze antenna and to its image respectively; n is the magnitude of the

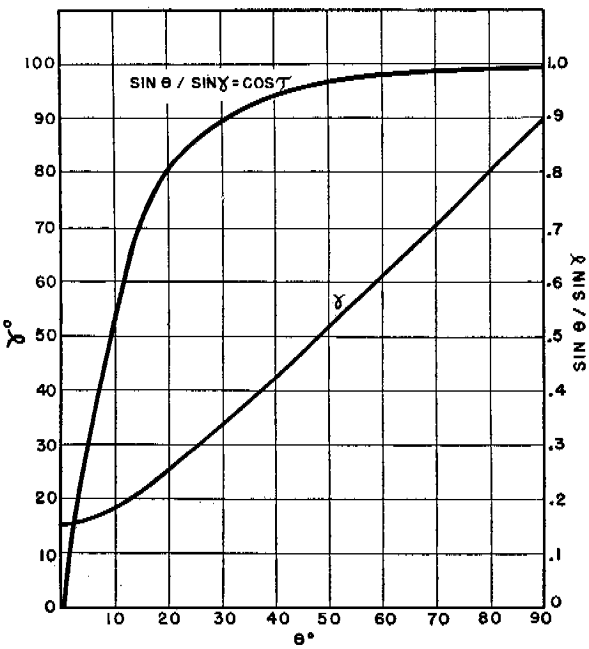


FIGURE 48. γ and $\cos \tau$ versus θ.

reflection coefficient, appropriate to the type of ground under consideration; Φ is the phase angle associated with this reflection; $\beta = (2\pi/\lambda)$.

The image representation used here does not fully represent the changes in polarization occurring at reflection when $n \neq 1$. An examination of the geometry shows that the receiver dipole responds only to the component of the electric field that is parallel to the ground at reflection. The vertical component whose absorption is most sensitive to ground properties is ignored. Thus we may safely use the image representation with an effective reflection coefficient n. It may be noted also that this coefficient is a constant for all angles θ of the transmitter, since the angle of reflection to the receiver is not altered.

A square law detector is used, so that the

[redacted]

measured directivity pattern, when normalized to unity, is given by

$$\frac{|E_t(\theta)|^2}{|E_t|^2_{\max}},$$

where $|E_t|_{\max}$ is the maximum value of $|E_t|$. What is desired, however, is the true pattern given by

$$\frac{|E_d(\theta)|^2}{|E_d|^2_{\max}} = f^2(\theta).$$

Now n/r may be written as N/a, where N, as

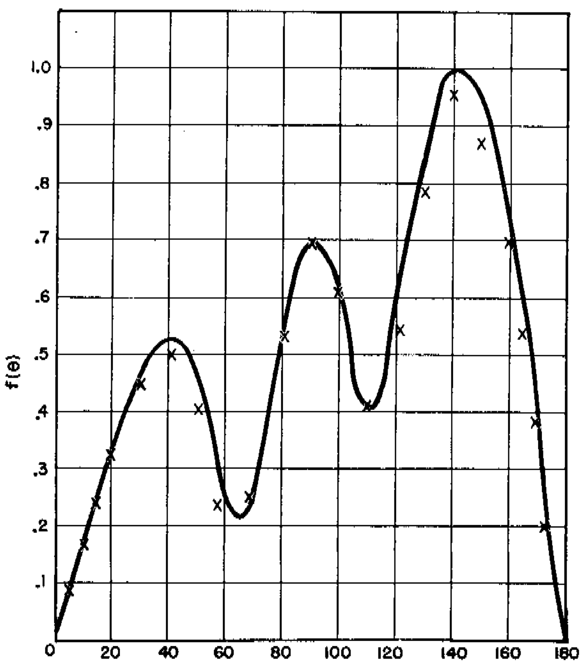


FIGURE 49. $f(\theta)$ and $f(\gamma)$ cos τ for electrically long antenna.

thus defined, differs in general by a few per cent from n. We may then write

$$E_t(\theta) = \frac{A}{a}\, e^{j[\omega t - \beta a - \epsilon(\theta)]}.$$

$$\left\{ f(\theta) + Nf(\gamma)\,\frac{\sin\,\theta}{\sin\,\gamma}\, e^{j[\Phi_1 - \epsilon(\gamma) + \epsilon(\theta)]} \right\}, \qquad (170)$$

where we have defined

$$\Phi_1 = -\beta(r-a) - \Phi.$$

Then

$$|E_t(\theta)|^2 = A' \left[f^2(\theta) + N^2 f^2(\gamma)\,\frac{\sin^2\,\theta}{\sin^2\,\gamma} + 2Nf(\theta)f(\gamma)\,\frac{\sin\,\theta}{\sin\,\gamma}\cos\,(\Phi_1 + \epsilon(\theta) - \epsilon(\gamma) \right], \qquad (171)$$

where A' is a new constant of proportionality. Thus

$$\frac{|E_t(\theta)|^2}{|E_t|^2_{\max}} = \frac{q}{q_{\max}}, \qquad (172)$$

where q is the expression in brackets in equation (171).

When the fuze antenna has the pattern of an elementary dipole, we have

$$f(\gamma) = \sin\,\gamma, \qquad (173)$$

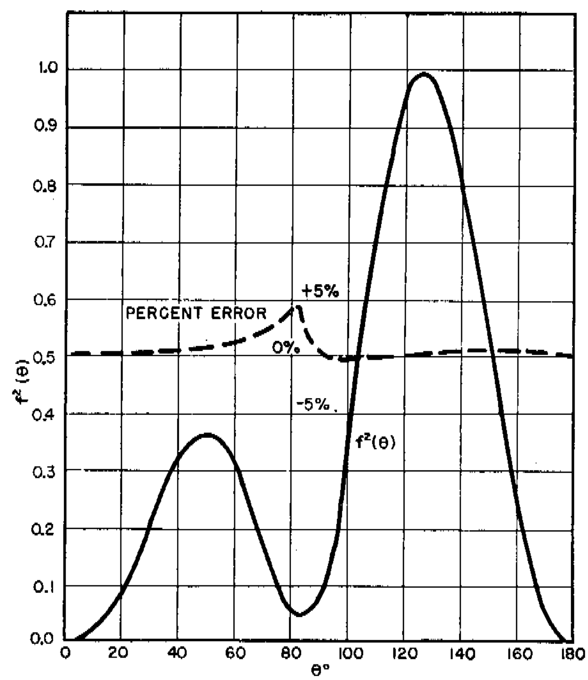


FIGURE 50. Typical theoretical pattern $f^2(\theta)$, with per cent error due to ground reflection.

which makes

$$f(\gamma)\,\frac{\sin\,\theta}{\sin\,\gamma} = f(\theta). \qquad (174)$$

Furthermore, there is no phase dependence on θ; that is

$$\epsilon(\theta) - \epsilon(\gamma) = 0. \qquad (175)$$

Then

$$q = f^2(\theta)\,[1 + N^2 + 2N\cos\,\Phi_1], \qquad (176)$$

so that

$$\frac{|E_t(\theta)|^2}{|E_t|^2_{\max}} = \frac{f^2(\theta)}{f^2(\theta)_{\max}} = f^2(\theta). \qquad (177)$$

Thus for this limiting case, the errors reduce to zero.

We have seen that when the conditions of equations (174) and (175) hold the errors reduce to zero. In practice, for the fuze antennas in use, these two conditions are so nearly fulfilled that the errors are small. Figure 49 is an example of how nearly equation (174) is fulfilled, even in the case of complicated patterns. The solid line represents a three-lobed pattern $f(\theta)$ obtained with an electrically long projectile. Although this is an observed pattern, it represents a possible true pattern. The crosses are the values of $f(\gamma)\cos\tau$ obtained by utilizing the relations in Figure 48. For simpler patterns the differences between $f(\theta)$ and $f(\gamma)\cos\tau$ are less than those in Figure 49.

It was mentioned in Section 2.8.2 that theoretical patterns representing very good fits for the observed patterns may be obtained by assuming a current distribution of the form shown in equation (98). Such computations afford a means of estimating $\varepsilon(\theta) - \varepsilon(\gamma)$ and also $f(\gamma)\cos\tau$. Such calculations over a range of conditions indicate that $\varepsilon(\theta) - \varepsilon(\gamma)$ does not exceed 5 degrees for patterns now in use. By using the values thus found and combining them with a range of assumed values for Φ, and n, values of q/q_{max} may be computed. Such computations lead to the conclusion that the error from those sources will rarely be in excess of 5 per cent.

Figure 50 is an illustration of the extent of the errors found by such considerations. The solid line represents the $f^2(\theta)$ calculated from the type of current distribution mentioned, with R and δ chosen to give a typical bomb radiation pattern. The dashed curve represents the percentage of error obtained by assuming $\Phi = (\pi/2)$, $n = 1$, values which give approximately maximum errors. The percentage of error curve is a plot of

$$100\left[\frac{q/q_{max} - f^2(\theta)}{f^2(\theta)}\right] \text{ versus } \theta.$$

Chapter 3

ELECTRONIC CONTROL SYSTEMS[a]

THE BASIC PHYSICAL phenomena underlying the production of an actuating signal for a doppler-type radio fuze have been discussed. This chapter is concerned with the problems of designing electric circuits to convert the signal so that a missile will be detonated in accordance with the military requirements. In the preceding chapter it was shown that the interaction between a radiating system and a reflecting target can be considered as a load variation across the two terminals connecting the antenna with the oscillator. The variations in load occur at an audio rate. The problem of this chapter is to show how the variations in antenna load are converted to a signal which will detonate the missile at the proper point on its trajectory.

There are five major subdivisions in this chapter:

1. The r-f section which treats of the design of oscillator detector circuits which respond properly to variations in loading.
2. The audio-frequency section which discusses methods of controlling the load-variation signal so that it will reach the proper amplitude at the proper time.
3. The detonator section in which it is shown how an audio signal of requisite amplitude initiates an explosive train.
4. The power supply section in which ways and means of supplying electric energy to the electronic circuits are described.
5. A coordination section in which the various design compromises are discussed.

3.1 RADIO-FREQUENCY SYSTEMS[b]

3.1.1 General Requirements of the R-F Unit

The r-f system was originally conceived as a combined transmitter-receiver, converting the target-approach doppler frequency into an audio-frequency signal by rectification. The circuit engineering is simplified by viewing the net electromagnetic behavior of the radiating missile as a two-terminal variable impedance. For practical purposes, it is sufficient to consider this impedance as the parallel combination of a constant reactance and a variable radiation resistance. The fixed reactance branch can be mentally combined with the transmitter circuit, simplifying the problem to that of an oscillator feeding a variable resistance load.

The net radiation resistance load is a function of fuze and missile dimensions as well as operating frequency. The fuze and missile combinations in use lead to radiation loads ranging from 1,500 to 150,000 ohms, a total range of two decades. In general, the low end of this range is associated with long missiles, such as the larger rockets and bombs; the medium range (up to 20,000 ohms) is associated with medium size bombs; and the upper range with the small mortar shells. The extreme case of 150,000 ohms is contributed by the fuzes using transverse-dipole or loop antennas. The small mortars present radiation resistances from 6,000 to 100,000 ohms, by virtue of the extreme frequency range used.

The most severe aspect of the large load range is its effect on the design of a "universal" fuze. A fuze designed for interchangeable use on all bombs must operate satisfactorily over at least a tenfold range of values of load resistance. When the use of a fuze is limited to a specific missile, the circuits can be designed for the optimum match between source impedance and load. The goal of semiuniversality, to reduce the required number of models, places a severe limitation on the types of r-f systems that can be employed.

The most elementary r-f system for a proximity fuze consists of a low-power oscillator, relatively heavily loaded. This may be considered to be an "oscillating detector" and is operated under approximately the same condition

[a] This chapter, which consists of five major sections, was prepared by several different authors. They are named in footnotes to the headings of the various sections.

[b] This section was prepared by Chester H. Page, of the Ordnance Development Division of the National Bureau of Standards.

as utilized for autodyne reception of telegraphic communications. The basic design consists of an oscillator with little regeneration, operating under Class A grid conditions, developing its own grid bias across a large grid leak resistor (of the order of a megohm). The plate current is supplied through a resistor of some 50,000 ohms. The coupling between the oscillator and antenna is sufficiently tight to place the oscillator on the verge of instability from overload. Under these conditions the plate current (and therefore the plate potential also) is a sensitive function of load resistance. Such a scheme allows the conversion of radiation resistance variation into an audio signal appearing across the triode plate circuit resistor. The fundamental weakness of this circuit arrangement lies in the small range of radiation load for satisfactory operation. This precludes its use in semi-universal fuzes, and also leads to critical load coupling adjustment. Little attention has been paid to this type of circuit.

Another circuit based on the concept of separate functions of transmission and reception used a stable power oscillator inductively coupled to the antenna circuit. A tuned diode detector was also coupled to the antenna circuit for rectification of the doppler frequency beats. Very early in the program, it was realized that the transmission-reception-detection problem could be considered as a variable antenna resistance problem, as previously discussed. This realization led to a simplification of the circuit, by combining the tuned diode circuit and antenna coupling functions. The new arrangement comprised a tuned diode voltmeter across the antenna terminals, with the diode-antenna tuning coil inductively coupled to a stable oscillator operated at full power. This arrangement required an adjustable vernier tuning capacitance for individually resonating the diode-antenna circuit to the particular oscillator assembly. Aside from production problems and effects of aging on the tuned circuit, this design leads to difficulty for semi-universal application by virtue of the different antenna reactance presented by different missiles. Although this reactance variation for one family of missiles is not large, it is sufficient to produce appreciable detuning of the sharply resonant diode circuit.

A further simplification of the fuze was based on the dependence of grid voltage of an oscillator on its load. Details of a practicable circuit were worked out in cooperation with Andrew Stratton of the British Ministry of Aircraft Production during an extended visit to the National Bureau of Standards [NBS].[79, 88] If the oscillator is operated under appropriate conditions of grid current and grid bias, its plate current is insensitive to load, but its grid bias exhibits a smooth reproducible dependence on load. This is, of course, a variable efficiency oscillator. The bias developed is almost exactly proportional to the voltage developed across the antenna. The antenna is tightly coupled to the oscillator, and the lack of sharply resonant coupling circuits makes the system insensitive to small antenna reactance differences. For the same reasons, operation is not sensitive to frequency differences among individual oscillators, and no vernier tuning adjustment need be made. This so-called *reaction grid detector* [RGD] circuit was used in all the later models of proximity fuzes developed by Division 4.

A second type of oscillator reaction which can accommodate a wide load range was developed and employed by the Westinghouse Electric Corporation.[111, 205, 206] This circuit is superficially the original oscillating detector with the plate resistor replaced by the primary winding of an audio transformer. It differs in the operating conditions of the triode. The plate current and generated power are considerably higher than in the oscillating detector, but the variation of plate current with load is still employed as the signal generating means. This circuit is referred to as the *power oscillating detector* [POD]. The signal voltage generated by the load resistance variation is the equivalent plate circuit voltage which would produce the observed current variations through the transformer impedance and triode plate resistance. The grid operates under Class A conditions, instead of the heavy Class C condition utilized in the RGD circuit.

3.1.2 Sensitivity

DEFINITION OF SENSITIVITY

One fuze will be called more sensitive than another fuze if it will function further from

[redacted]

the target, all conditions of use being the same. This is a purely qualitative concept, which can be made quantitative in various ways. For example, the "Michigan sensitivity" (see Section 2.11) of a fuze is the theoretical function height over a perfect reflector of infinite extent with the missile approaching the target plane in the most favorable aspect and with the speed appropriate to the most favorable doppler frequency (audio-amplifier response). The function height under practical conditions is predictable from the Michigan sensitivity by ratio computations. This definition is still too general for our needs. What is desired is an absolute definition of the sensitivity of the oscillator to radiation load changes as shown in Section 2.7. This relates a given physical situation to the audio signal voltage produced by the oscillator system. The knowledge of this voltage, together with the known characteristics of the amplifier and thyratron, allow the prediction of function heights in a straightforward manner as shown in Section 2.9. The r-f system acts as a means of converting a physical electromagnetic situation into an electric circuit problem. In this work, the unqualified term "sensitivity" has been restricted to the sensitivity of this converter and has been defined as the developed signal voltage divided by the fractional change of load resistance resulting in this signal[7] [equation (84) of Chapter 2]. Mathematically it is defined for infinitesimal load changes and is the derivative of the operating voltage whose changes become the audio signal, thus:

$$S = \frac{dV}{dR/R}. \tag{1}$$

Since V is the voltage (grid bias or diode output) at the operating point, and dR/R is dimensionless, the sensitivity is expressed in volts. Rewritten in the following form it is the same as equation (84) in Chapter 2.

$$S = \frac{dV}{d \ln R}, \tag{2}$$

where $\ln R$ refers to the natural logarithm. This form of the definition is more useful, since it shows the sensitivity of the oscillator to be the slope of its "load curve" plotted on natural semilog paper.

We are concerned here primarily with sensitivity due to load resistance changes rather than load reactance changes. The possible effects of the latter are discussed in Section 3.1.

It has been found that properly designed *oscillator-diode* [OD], RGD, and POD systems behave like ideal generators of fixed internal resistance, with the d-c operating voltage proportional to the load voltage.[111] This idealized r-f unit is quite amenable to mathematical analysis, and some interesting general relationships are derivable.

Let us consider the behavior of a constant-current generator with internal (shunt) resistance R_i and unloaded terminal voltage V_∞. The terminal voltage for any load is propor-

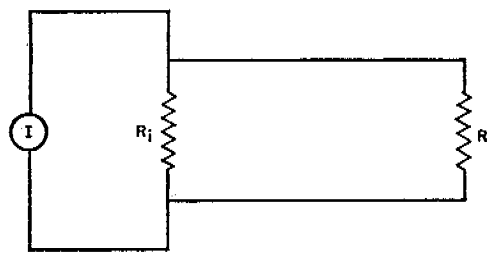


FIGURE 1. Circuit with constant current generator and shunt load.

tional to the net resistance of the load and R_i in parallel (see Figure 1). Hence, operation under load R yields the voltage

$$V = \frac{V_\infty}{R_i}\,\frac{RR_i}{R + R_i} = V_\infty\,\frac{R}{R + R_i}. \tag{3}$$

The sensitivity may be found from equation (1)

$$S = R\frac{dV}{dR} = V_\infty \frac{RR_i}{(R + R_i)^2} = V_\infty \frac{V}{V_\infty}\left(1 - \frac{V}{V_\infty}\right)$$
$$= V_\infty\,\rho(1 - \rho), \tag{4}$$

where ρ is the "loading ratio," or the ratio of loaded (operating) voltage to unloaded voltage.

The term V is, of course, the operating voltage under radiating conditions, and V_∞ the voltage when the fuze is properly shielded so that the oscillator does not radiate.

The final form of equation (4) shows that loading to one-half the unloaded voltage yields the maximum sensitivity for a given oscillator but that this adjustment is not critical (see Figure 2). This loading ratio is also the condition of maximum radiated power, or the con-

[redacted]

dition of matching the load to the internal resistance. The problems involved in obtaining this match by the use of an impedance transforming network between oscillator and antenna will be discussed later.

A load curve (a plot of operating voltage versus the logarithm of the load resistance) for the ideal generator is shown in Figure 3. It is seen to be a symmetrical S curve. For purposes of comparing actual generator performance with this ideal characteristic, such a curve is not convenient. The ideal case can, however, be expressed as a linear relation, allowing easy evaluation of experimental data. This form is derived from equation (3) by algebraic manipulation and is

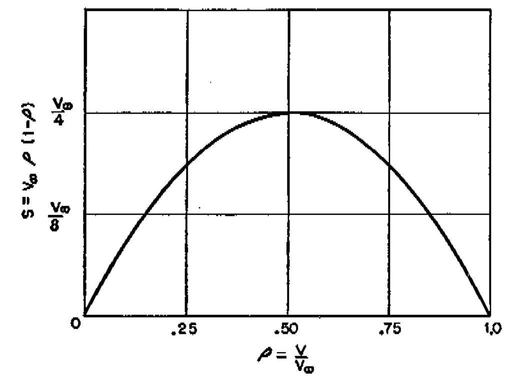


FIGURE 2. Variation of sensitivity S with loading ratio ρ.

$$\frac{1}{V} = \frac{1}{V_\infty} + \frac{R_i}{V_\infty}\frac{1}{R}, \tag{5}$$

so that a plot of $1/V$ versus $1/R$ is a straight line whose intercepts are $1/V_\infty$ and $-1/R_i$. This form is exceedingly convenient for smoothing experimental data and for determining the internal resistance (R_i) of an oscillator.

This representation of ideal generator behavior allows easy comparison of actual performance data with the idealization. Good RGD oscillators follow this relation quite well over the load range for which their plate current is constant. If the feedback in the oscillator is not optimum, the plate current will vary with load. It has been found that in this case I_p/V is a linear function of $1/R$. Since the grid bias is normally obtained across a grid resistor with ground return, it is proportional to grid current, and the above relations would have the same form expressed in terms of grid current instead of grid bias. In the special case where the grid resistor is returned to an initial bias, usually positive, the grid bias and grid current are no longer proportional, but are linearly related. Equation (5) is then no longer valid. A plot of I_p/V_g versus $1/R$ is concave upward (for positive initial bias), while a plot of I_p/I_g is concave downward. A straight line is yielded by plotting $I_p/\sqrt{I_g V_g}$ versus $1/R$.

For the normal grid resistor connection, the result that I_p/V_g is a linear function of $1/R$ can be directly interpreted to mean that the oscillator is a current generator of fixed internal resistance whose current is proportional to the triode plate current. The results of the more complicated case where an initial bias is used imply that the proportionality between grid bias and the fictitious terminal voltage is not the basic relation but that the general phenomenon is proportionality between grid power and the square of the terminal voltage. This covers all the above cases.

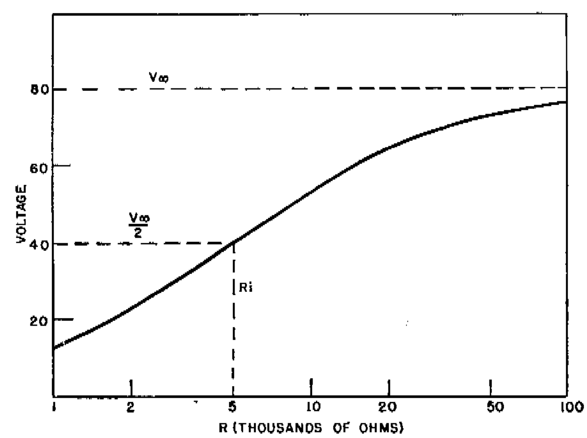


FIGURE 3. Loading curve for ideal generator.

These relationships, equation (5) and modifications, are not directly applicable to the POD oscillator, where the variation of plate current with load is the signal generating means. Examination of experimental data for this system[111] showed the plate current I_p to be a linear function of $1/R$ over the load range of interest (see Figure 4). The equivalent signal voltage in the plate circuit is readily computable from

the total plate circuit resistance, so that the effect of the transformer primary impedance at any audio signal frequency can be easily taken into account. These results are mathematically expressed as

$$
\begin{aligned}
I &= I_\infty + \frac{b}{R}, \\
V &= R_p I = R_p\left(I_\infty + \frac{b}{R}\right), \qquad (6) \\
S &= \left|R\,\frac{dV}{dR}\right| = R_p\,\frac{b}{R} \\
&= R_p\,(I - I_\infty) = E_B\left(\frac{I}{I_\infty} - 1\right).
\end{aligned}
$$

The justification for replacing $R_p I_\infty$ by the supply voltage E_B in the last step is experi-

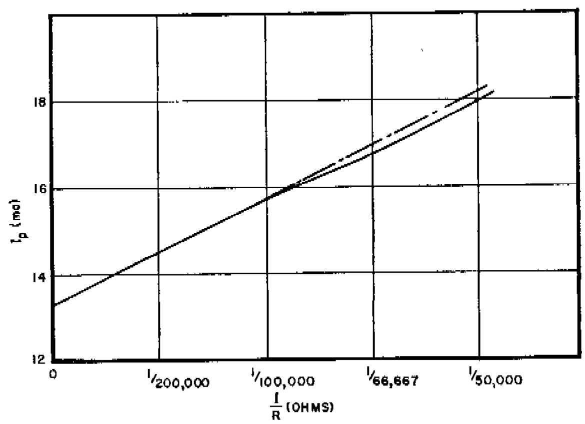


FIGURE 4. Loading curve (for POD generator) plotted against reciprocal load. Relation over range of interest (i.e., resistance values above 100,000 ohms) is linear. For lower resistance values, solid line represents actual values, dashed line represents ideal linear extension.

mental. Measurements of I_∞ versus E_B on production assemblies showed that the dynamic plate resistance R_p was equal to the static plate resistance (E_B/I_∞) under the operating conditions of this oscillator.

The direct practical application of all the above sensitivity formulas is limited by the fact that the radiation resistance is not a free variable. If it were, it could be chosen to match the source resistance, and maximum sensitivity and power radiation would be obtained. The oscillator design problem would then essentially reduce to the problem of designing for maximum grid bias under no load.

The radiation resistance of transverse antennas is restricted to high values by the small dimensions involved. On the other hand, the radiation resistance of longitudinally excited antennas is adjustable through a considerable range of values by variation of the size of the exciting end cap. Unfortunately, for a given overall fuze length, increasing the length of the end cap involves decreasing the separation between the end cap and the missile. (The effect of geometry of the end cap on antenna reactance has been shown in Figures 4, 12, and 13 of Chapter 2.) This increases the shunt capacity presented to the oscillator and decreases the internal resistance that can be had. There is obviously some optimum compromise between radiation resistance and shunt capacity for a fixed set of oscillator design factors.

For a given cap and oscillator, the use of a matching network suggests itself. Practically, the network losses frequently cancel the expected gain of sensitivity. The general properties of this phenomenon are readily derivable. Let us assume an antenna of resistance A connected to a simple generator of voltage E by

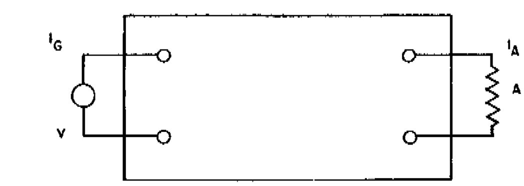


FIGURE 5. Block diagram for matching network for generator and antenna.

way of a passive four-terminal network, as shown in Figure 5.

The input resistance of the network is given by $R = V/I_G$. We are interested in the value of dR/R for a given dA/A. We note first that

$$dR = -\frac{V}{I_G^2}\,dI_G \quad \text{and} \quad \frac{dR}{R} = -\frac{dI_G}{I_G}. \qquad (7)$$

The effect of increasing A by a small change dA is the same as would result from the introduction of a voltage $de = I_A dA$ into the output circuit. The incremental generator current dI_G produced by de is, by the reciprocity theorem, the same as the increment dI_A that would result from the introduction of de into the input circuit. If we summarize certain properties of the

[redacted]

particular network in terms of a transfer constant T, so that

$$I_A = TV, \quad dI_A = TdV, \tag{8}$$

we readily find

$$dI_G = -TI_A dA. \tag{9}$$

To evaluate equation (7) we need an expression for I_G in terms of I_A. This is obtained in terms of the network efficiency. The power input is VI_G, and the power output is $I_A{}^2A$. Hence, the power transfer efficiency of the network is given by

$$\epsilon = \frac{I_A{}^2A}{VI_G} = T\frac{I_AA}{I_G}. \tag{10}$$

Combining equations (7), (9), and (10) gives

$$\frac{dR}{R} = \epsilon\frac{dA}{A}, \tag{11}$$

so that the power transfer efficiency ε of the network is also the sensitivity transfer efficiency.

This result suggests the existence of a general relation between sensitivity and radiated power, the source being unchangeable. We can generalize the oscillator circuit as comprising a triode, coupling network, and antenna. Viewed in this light, the idling bias V_∞ is determined by supply voltage and tube design and does not depend upon circuit losses. We assume throughout that the grid drive conditions are such that the tube behaves as a constant-resistance generator. This implies for the RGD that the plate current is approximately independent of load.

The generalized circuit is shown in Figure 6, using the constant-current generator representation for convenience. The network is characterized by the two parameters T and ε, previously defined. The net effect of the antenna and network is to present a resistance R to the generator, as indicated in Figure 1.

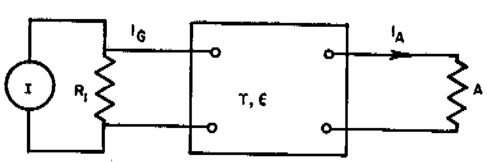


FIGURE 6. Generalized circuit arrangement for coupling generator and antenna.

We have the following starting point relations:

$$I_A = TV, \tag{8}$$

$$RI_G = V,$$

$$\epsilon I_G = TI_AA, \tag{10}$$

$$V = V_\infty\frac{R}{R + R_i}. \tag{3}$$

We immediately derive[c]

$$R = \frac{\epsilon}{AT^2}. \tag{12}$$

Further, utilizing equation (11), we have

$$S = \frac{dV}{dA/A} = \epsilon\frac{dV}{dR/R} = \epsilon V_\infty\frac{RR_i}{(R + R_i)^2}. \tag{13}$$

Now the radiated power is

$$P_A = I_A{}^2A = T^2V^2A = T^2V_\infty{}^2A\frac{R^2}{(R + R_i)^2}, \tag{14}$$

so that

$$\frac{S}{P_A} = \frac{\epsilon R_i}{T^2V_\infty AR} = \frac{R_i}{V_\infty}, \tag{15}$$

and is independent of T, ε.

This result is of great interest and is in agreement with intuition. For given triode operating conditions, the sensitivity is proportional to the power radiated. The components in the network can be adjusted for maximum voltage across the load resistance, and the sensitivity will be maximized. The unavoidable practical interdependence of T and ε does not affect the relation between sensitivity and power.

The above discussion reduced the ideal generator to the triode itself, with V_∞ essentially a tube parameter. In practice, the idling bias V_∞ is defined as the bias with the radiation load A removed but all other network components untouched. This practical definition is needed, since the presence of the network is required for oscillation. From this experimental viewpoint, the effect of the network transfer constant is to adjust the internal resistance as seen by the antenna. The inefficiency of the network is expressible as a fixed loss load shunted

[c] Equation (12), if differentiated, would imply $(dR/R) = (dA/A)$. This procedure is not legitimate, since both T and ε are functions of A.

across the antenna. This reduces the laboratory idling bias and also lowers the source resistance as seen by the antenna. It has been found that attempts to increase the step-up ratio of the network also increase the losses of the network, so that the optimum circuit arrangement for high-resistance antennas is a compromise between high bias and load matching.[118, 121]

Experimental Determination of Sensitivity

Throughout the early stages of the development, all measurements of sensitivity were measurements of the combined effects of oscillator and antenna performance. Reference is being made to the pole-test procedure discussed in Chapter 2. It suffices to repeat here only that this is a direct measurement of the signal voltage generated upon approach to ground. When suitable r-f load resistors became available, and the radiation resistance had been measured, the oscillator sensitivity S as determined in the laboratory was found to check closely with its value derived from the pole tests. (The derivation is the reverse of the process of predicting function height for a given oscillator sensitivity.) The experimental difficulties of pole-testing, in combination with ground screen diffraction effects, generally make this test method less accurate than the laboratory evaluation. Laboratory tests are also much quicker and much more convenient, especially when several parameter adjustments are being compared.

Standard laboratory oscillator testing includes taking a load curve and measuring the grid bias for various load values. The values used form a geometric sequence so that the data points are uniformly spaced on semilog paper (see Figure 7). Since standard commercial log paper is logarithmic to the base ten, the slope $dV/d(\log R)$ must be multiplied by $\ln 10 = 2.303$ to obtain the sensitivity S, which is $dV/d(\ln R)$. The sensitivity can, however, be conveniently read from a tangent to the curve by noting the change of ordinate along the tangent corresponding to two abscissas whose ratio is $e = 2.718$. Thus holding a straightedge tangent to the load curve at the point of interest and noting the intercepts of the straightedge with the vertical lines $R = 1$ and $R = 2.7$, or $R = 3.7$ and $R = 10$ allows computation of the sensitivity as the difference of the ordinate values of these intercepts.

Proximity fuze oscillators, like any transmitters, are tested on dummy radiation loads. The reaction-type units RGD and POD are insensitive to small load reactance errors and can be tested on resistor loads. The ultra-high-fre-

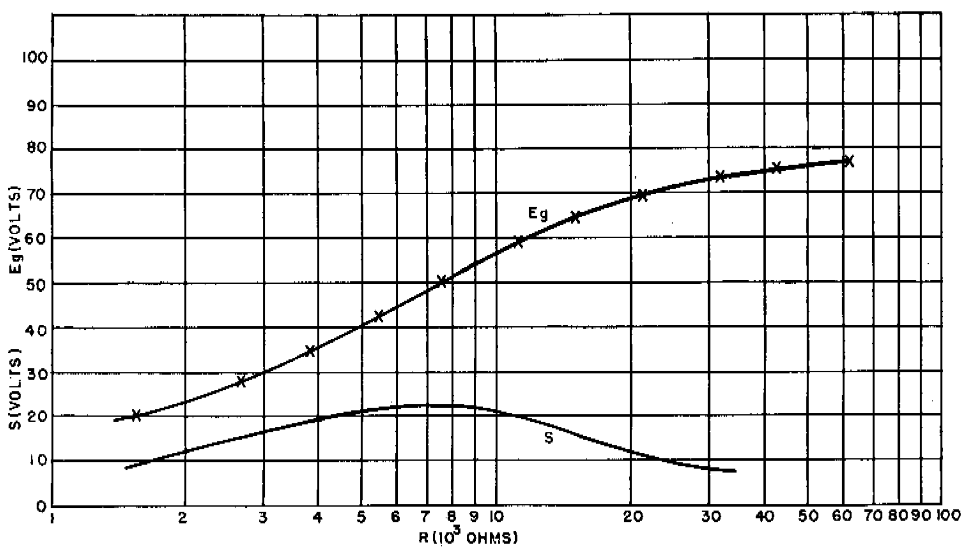


FIGURE 7. Typical data points for experimentally determined loading curve (E_g). Curve labeled S shows sensitivity or slope of E_g curve.

[redacted]

quency resistors of the ½- and 1-watt size, F-½ and F-1, manufactured by the International Resistance Corporation, have been found satisfactory. Although the true values of these resistors at high frequency are not the same as the d-c values, the percentage difference does not vary seriously with resistance value. As discussed in Chapter 2, this allows the employment of a self-consistent set of resistors wherein the unit is only approximately the ohm. Since radiation resistances are automatically measured in terms of this same unit, proper dummy loading and load curves are readily obtained.

In the case of oscillator-diode type fuze, wherein the antenna circuit is sharply resonant, the dummy antenna must present not only the correct resistive component but also the correct reactive component of impedance. For various practical reasons, such as keeping r-f currents out of the power supply leads and metering leads, it has been found necessary to shield the fuze exciting cap properly from the laboratory environment. Enclosure of the fuze oscillator head in a metal shield box normally introduces more antenna shunt capacity than is introduced by mounting the fuze on a missile. To compensate for this, a low-loss inductor is made a part of the dummy antenna and shunted across the fuze to be tuned or measured. This inductor is designed to parallel resonate the excess capacity introduced by the shield box. The power loss in the inductor is compensated by appropriate choice of dummy load resistor, so that the resistive component of the inductance combines with the test resistance to present the correct net load.

For test operation of the complete metal parts assembly of a fuze, the shield box must be rigid and relatively small. (The shield box for tuning adjustments forms a 2-ft cube.) Since the fuze is vigorously vibrated in the final test chamber to search out microphonic defects, a directly connected dummy antenna is not usable. The simulated load is capacitatively coupled to the exciting cap, and the load impedance is connected between the pickup plate and the chamber. The inductive and resistive components of this impedance must be empirically adjusted for proper operation. The operating grid bias (or diode voltage) is measured as a quality check, but no actual sensitivity measurement is made. The voltage check for production consistency is sufficient with a sampling test for oscillator sensitivity.

The load curve slope determination of sensitivity is an indirect measurement. Several schemes for direct dynamic measurement of sensitivity have been proposed. These are all based on the use of a resistance which varies sinusoidally at an audio-frequency rate and can, therefore, be used either for measuring oscillator sensitivity or the overall Michigan sensitivity of the fuze. As all these direct dynamic methods of measuring sensitivity are necessarily signal simulators, they have already been discussed in Section 2.12.[10]

One dynamic loading arrangement not in this category has had laboratory use. It is a device that allows the load curve to be exhibited on an oscilloscope, showing the existence of any oscillator instabilities and generally simplifying the process of investigating component changes. The desired load curve is voltage versus logarithm of resistance. If the load resistance is caused to vary exponentially with time, then time becomes proportional to the logarithm of the load resistance, and the normal linear time base of the oscilloscope is appropriate for display of the voltage. The arrangement used comprised the dynamic plate resistance of a triode for the oscillator load, with an appropriate unidirectional pulse of exponential decay applied to the grid of the auxiliary triode. Correct choice of the fixed bias on the grid relates the dynamic plate resistance to the added bias in the desired linear fashion.

Practical Oscillator Design

It has not been found possible to design completely an RGD oscillator on paper. Certain adjustments must be empirically determined, and the associated phenomena are not thoroughly understood.

Experience has shown that adjustment of the oscillator parameters to make the oscillator behavior approach that of the ideal generator results in the greatest stability and reproducibility of operation. The feedback is adjusted by varying the plate circuit inductance to the

[redacted]

end that the plate current is substantially independent of load. There is a considerable range of grid drive (feedback) that will satisfy this condition.

Within this suitable range of operating conditions, we find that increasing the drive results in higher grid bias and plate current with lower internal resistance. The increase of bias tends to increase the sensitivity; the decrease of internal resistance usually tends to lower the sensitivity. This effect arises in the high-shunt radiation resistances encountered, leading to an increase of mismatch with decreased internal resistance.

These two conflicting factors lead to a relation between sensitivity and drive which has a maximum. In practice the oscillators have usually been designed empirically for this compromise of maximum sensitivity under normal radiation conditions.

The value of the grid leak resistor is optimized quite simply. Variation of the grid leak, *ceteris paribus,* results in a parallel variation of grid bias and an opposite variation in plate current. Thus larger leak resistances give higher bias with less plate current, hence also higher internal resistance, until a plateau is reached. Still larger resistance values give negligible improvement, and eventually lead to squegging. Fortunately, when antisquegg stabilization is used the plateau can be reached and still allow a safety factor of 2 for stability.

With the NR-3A triodes, 47,000 ohms was most commonly used for the grid leak. The T-51 fuze used a 33,000-ohm leak, with slightly higher plate current. (See Figures 14 and 15.)

3.1.3 Radiating System

The mechanical details of the radiating system have been discussed in Chapter 2 along with the corresponding field patterns and radiation resistance values. In this chapter, the effect of the choice of radiator upon circuit design will be discussed.

The original "whip antenna" was basically a trailing wire, base loaded with inductance. This presented a relatively low-radiation resistance, and was accordingly series tuned. The oscillator was inductively coupled to the antenna circuit. A tuned diode circuit was loosely coupled to a second point in the antenna circuit, thus providing a means of measuring the antenna current and its variations. This bomb tail fuze served to prove the feasibility of proximity fuzes and was soon discarded in favor of an engineered assembly.

The second stage in the development of the exciting arrangement was the substitution of a conical cap for the trailing whip. The impedance of this was sufficiently high to permit of parallel loading, the antenna feed points (cap and body) being connected across the diode tuning coil. Early models used a variable series coupling condenser between the cap and coil. This was done mainly to allow the vernier tuning adjustment to be made externally, the movable center screw of the simple cylindrical vernier condenser being threaded through a nut on the apex of the cap. Corona effects to be discussed later forced the abandonment of this scheme. The same arrangement was used in the first production of MC-382 rocket fuzes. In this case the corona problem was minor, but the mechanical instability of the condenser, and the complications of construction, left much to be desired. These several problems were solved by making the tuning adjustment from the base of the fuze, so that the cap could be direct-connected to the diode coil, and operate at d-c ground potential.

Further variations of the end cap resulted in the antenna ring used on T-50 and related fuzes. (See Figures 4 and 5 of Chapter 1.) This design yielded medium radiation resistance values, which were readily matched to the oscillator, with relatively low fixed shunt capacity. The ring also acted as a mechanical guard for the wind vane and as an electric shield against effects of bearing looseness and vane end-play.

The latest variation of the end cap is found in the T-132 and T-171 mortar fuzes. (See Figure 6 of Chapter 1.) In these designs the cap has grown in proportions until it is used as the housing for all components of the fuze except the oscillator and detonator mechanism. This makes it feasible to locate a turbo-generator power supply in the fuze nose.

[redacted]

An interesting antenna problem arose in the case of the 3-in. antiaircraft rocket. The insulated gap in this case was between the rocket motor and body, or about one-third of the total length from one end. The radiation resistance was of the order of 50 to 100 ohms. The location of the insulator required it to be mechanically rugged, and this automatically introduced high shunt capacity. The final design of insulating "coupler" had 40-μμf shunt capacity.

It had been found with experimental low-capacity couplers that series feed of the antenna was convenient. The antenna load was simply inserted into the ground return of the diode coil. Proper load coupling occurred for a total antenna shunt capacitance of about 15 μμf. All attempted designs of coupler not exceeding this capacity failed to meet mechanical strength tests, so that attention was turned to the high-capacity rugged designs.

The final 40-μμf design was incorporated into the circuit by shunt resonating 25 μμf of its capacity, leaving in effect a 15-μμf coupler. This tuning was noncritical and was accomplished by connecting approximately 1½ in. of heavy wire across the coupler.

Another exceedingly low-resistance antenna was encountered in experimental work on tail fuzes for the 4,000-lb and larger bombs (T-40 and T-43). The tail structure of these bombs is sufficiently large to be used as a shunt-excited portion of the antenna, the feed points being the end of the fin structure and the bomb body.

The remaining antenna structures are those designed for transverse excitation: the dipole and the loop. These both present exceedingly high parallel-radiation resistance, because their maximum dimensions are so small compared to the usable wavelengths. From the circuit standpoint, the loop is ideal. It is used as the plate-to-grid inductance of a Colpitts oscillator; the interelectrode capacitances complete the circuit. It has been found advisable to add capacity from triode grid to ground to balance the potential distribution of the loop and minimize longitudinal excitation. The loop is, however, a very inefficient radiator in such small dimensions. Its series radiation resistance varies as the fourth power of its radius, measured in terms of the wavelength.

Early dipole-exciting circuits used the dipoles as end loading of the grid-plate Colpitts oscillator coil. Higher sensitivity was obtained by inductively coupling a dipole loading coil to the oscillator coil. The two coils were interwound on a double-threaded form for close coupling. Maximum sensitivity was obtained by winding the antenna coil with about one turn more than the oscillator coil. The radiation resistance presented to the antenna coil is about 140,000 ohms. A convenient sensitivity check was made by noting the change of grid bias RGD or plate current POD when a 100,000-ohm load was presented to an otherwise unloaded fuze. Theoretically, two load voltage measurements bracketing the operating point are needed for a sensitivity approximation. (The approximation involved is that of replacing the tangent slope by a secant slope.) Both these load resistances must be finite. In practice, all oscillators operating at loads higher than 100,000 ohms can be checked satisfactorily by finding the voltage drop for the 100,000-ohm load. This is essentially an empirical measure of the response of the oscillator to light loads but can be justified as a good approximation to equation (4).

$$S = V_\infty \rho(1 - \rho) \doteq V_\infty(1 - \rho) = V_\infty - V, \qquad (16)$$

for $\rho \doteq 1$, i.e., light loading.

3.1.4 Tube Characteristics

General Requirements and Restrictions

Problems arising in the development of tubes for Division 4 radio proximity fuzes did not stem from technical considerations alone. Decisions of military policy at staff level introduced extraneous technical problems of sizable difficulty, as will appear from the following brief historical review.

In the first successful demonstration of the radio proximity fuze, February 1941, standard electronic tubes were used. These were obviously too large for fuze application and presented serious microphonic problems. Accordingly, cooperative programs were set up with Raytheon Production Corporation and the Sylvania Electric Products Corporation (then Hy-

grade-Sylvania) aiming at the design and production of small tubes with the desired electric and mechanical characteristics. First contacts were on the usual customer-to-manufacturer basis and did not involve development contracts. Practically any hearing-aid tube could withstand the low accelerations involved in the prospective bomb and rocket applications. The real problems were (1) reduction of microphony to an order of 30 db better than heretofore realized in the best hearing-aid tubes; (2) securing of extremely stable and relatively high-output oscillator performance from the small-sized tubes involved; and (3) the development of suitable diode and thyratron tubes.

The fuze circuit rendered microphony and self-noise in the triode oscillator of paramount importance, with diode and pentode microphonics of next importance and thyratron microphony of least importance. By the early summer of 1941, reasonably promising triode and pentode designs were under way and contractual arrangements had been made with the two companies and others for continued development on all four tube types. Such arrangements were handled through Division A, NDRC, of which Division 4 (then Section E) was a part.

Concurrently with this program, Section T, Division A, NDRC, conducted a parallel development program with these and other tube manufacturers on a similar family of tubes for the shell-type radio proximity fuze. Here special emphasis was placed on tube ruggedness, with the requirement that a setback of $20{,}000g$ should be successfully withstood. Tube microphony was apparently not as serious a problem for Section T use, partly because of a somewhat different lower power oscillator arrangement, but primarily because the centrifugal action of the spinning shell tended to keep the tube element supports in a fixed position.

On August 26, 1941, Dr. Richard C. Tolman, Chairman of Division A, NDRC, appointed a committee to coordinate the two tube programs with A. J. Dempster as chairman, L. Grant Hector representing Section T, and Harry Diamond representing Division 4, then Section E. Contractors were informed of this setup. Both programs were prosecuted in parallel with Section T emphasis on ruggedness and Section E emphasis on microphony and oscillator performance. It is of interest to note that elements of design introduced to make a tube nonmicrophonic go a long way toward making the tube rugged. The correlation is by no means 1-to-1 but, curiously, the reverse is not nearly so true, i.e., making a tube rugged does not insure freedom from microphony.

As will appear from the following more technical discussions, many of the expedients for making tubes nonmicrophonic, such as special filament tension springs, four-pillar base construction, etc., were known to the art but were also essential in the Section T program for making tubes rugged. High-level policy required that Section E tubes be designed so that in the event of prior compromise they would not reveal details of rugged tube design to the enemy. This policy was based on firm military considerations and was followed in good faith. However, it placed the Section E tube program in the anomalous position of having no recourse to certain technical expedients known to be available to the enemy.

Hence, up to the time the mortar fuze design was begun, problems of Section E tube design consisted of how to attain the desired electric and mechanical performance without making the tubes too rugged. Since maximum rocket setback was of the order of $400g$ and some safety factor was essential, it was specified that tubes should withstand $2{,}500g$ as a lower limit, but under no circumstances should such tubes withstand more than $10{,}000g$. The curious situation ensued wherein anything that made a tube "not too rugged" was greeted with delight and tested with the hope that it would not affect tube microphony. One exception, a GE microthyratron, simulating lighthouse tube construction, was permitted by common consent, since it was not used in the Section T fuzes and no expedient could be found whereby it would not withstand 20,000 to $30{,}000g$.

In addition to the general requirement that the tubes fail at high accelerations, the following types of structure (most of which were well known to the art) could not be used: (1) four-pillar construction for supporting grid and plate elements, (2) a coil spring cantilever

(mousetrap construction) for supporting the filament under proper tension, (3) cross-press construction for the lead end of the tube, and (4) grid sleeves and grid stops. (See reference 33 of Chapter 1.)

Triodes

The design starting points were the subminiature hearing-aid amplifier pentodes already in existence. Omission of the screen and suppressor grids and replacement of the filament by a more powerful one made a triode suitable for experimentation. The power requirements on the triode were so relatively heavy that Raytheon put in two filament strands to obtain the desired emission and life.

The final design of the Raytheon tube was designated NR-3A and has approximately the following characteristics.

Filament voltage	1.4 v nominal	
Filament current	220 ma	
Amplification factor	8.3	at —7.5 v bias
Mutual conductance	1,600 micromhos	at —7.5 v bias
Cutoff bias	—23 v	

The above data were obtained at the nominal plate voltage of 140.

A photograph of the NR-3A triode is shown in Figure 8 and of the subassembly of the same tube in Figure 9.

The Sylvania triode NS-3, which was used in MC-382 battery fuzes but not in generator-powered fuzes, has approximately the following characteristics at nominal plate voltage of 140.

Filament voltage	1.4 v nominal	
Filament current	140 ma	
Amplification factor	9.3	at —6.5 v bias
Mutual conductance	1,350 micromhos	at —6.5 v bias
Cutoff bias	—15 v	

This tube was not used in bomb fuzes because of its low microphonic stability. This point will be discussed later.

These triodes work well in any of the standard oscillator circuits. The oscillator-diode type fuzes used the quasi-Hartley circuit shown in Figure 10. If the grid-filament and plate-filament interelectrode capacities were negligible, this would be a Hartley oscillator using the grid-plate capacitance as the "tank" condenser. In practice the first two capacitances are of the same order of magnitude as the last, so that the interelectrode capacitances have considerable effect on the feedback. The circuit can be considered as a Hartley with additional capacitance across the plate and grid coils or, equally,

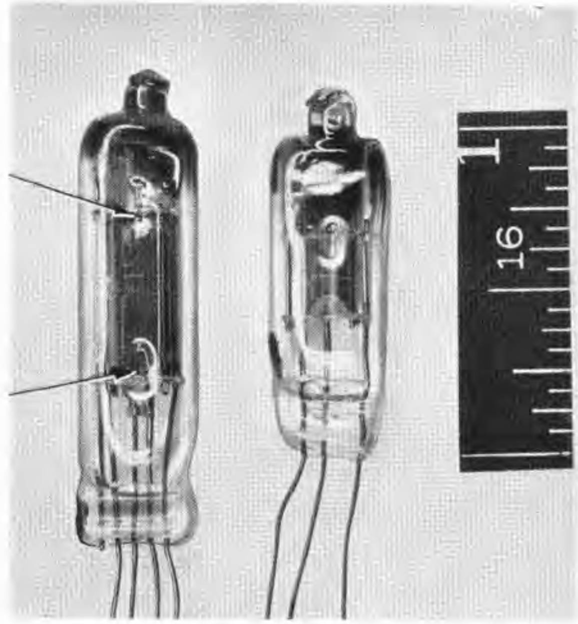


FIGURE 8. NR-3A triode (left) and NR-2 diode (right). Arrows show crimps to support mica spacers. Scale shown is 1 in.

as a Colpitts with an added coil tap. If the inductive feedback ratio is not equal to the capacitative feedback ratio, local circulating cur-

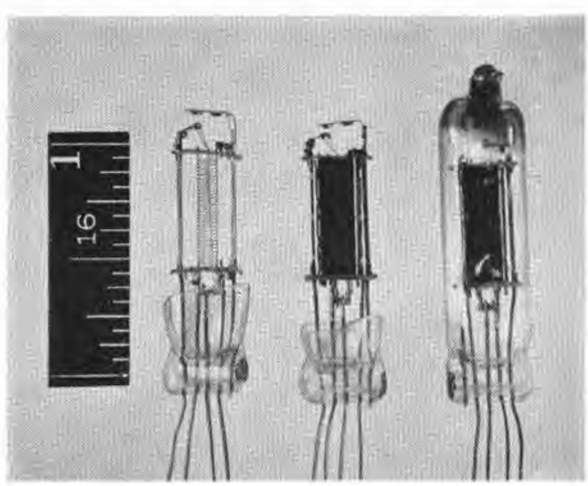


FIGURE 9. NR-3A triode with envelope removed.

rents are created in the grid and plate branches of the circuit, introducing extra power losses and sometimes critical response to coil adjust-

ments. This circuit operated satisfactorily in the 120- to 140-mc range, but was unsatisfactory at 150 mc.

Later circuits, RGD and POD, used pure Colpitts connections (cf. Figures 11 and 12). These perform quite uniformly over the whole range of 50 to 200 mc that has been used. For stable efficient operation, the NR-3A triode requires driving to approximately 2-ma average grid current. That is, in the oscillator-diode arrangement, where a low-impedance power source was required, the maximum usable grid leak was 15,000 ohms and the minimum bias for proper operation was 30 v, corresponding to 2-ma direct grid current. In practice, this

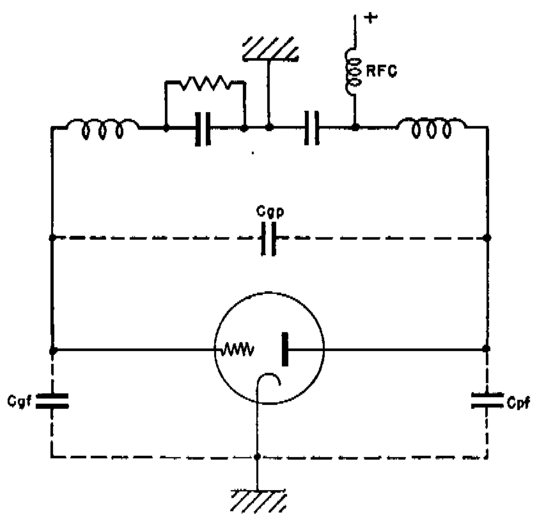


FIGURE 10. Typical quasi-Hartley oscillator used in oscillator-diode fuze circuits.

current fell between 2 and 3 ma. In the RGD oscillator, grid leaks of 33,000 and 47,000 ohms have been used with the idling bias in the range 60 to 100 v, so that the grid current under no load conditions was 1.5 to 2 ma. Since the optimum grid drive is affected by many factors, such as power output, internal resistance of the oscillator as a generator, stability of oscillation, and sometimes maximum grid bias, it is not determinable from any simple theory of the oscillator. It is, therefore, a purely empirical observation that, in general, the NR-3A should operate at about 2-ma grid current (this is for a nominal plate supply of 140 v).

The plate current of this triode may be anything in the range 7 to 14 ma, depending on the oscillator frequency and application. The subject triode has not been found useful at

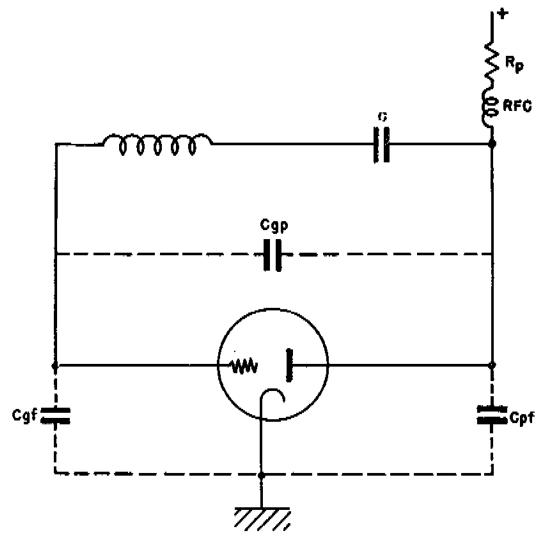


FIGURE 11. Typical Colpitts oscillator used in RGD fuze circuits.

lower plate current because of power (and sensitivity) requirements. Higher plate current does not normally occur with optimum oscillator design, but the average current for actual fuze designs has been found to be approximately proportional to oscillator frequency in a given type of application and circuit.

All electric circuits are in some degree sub-

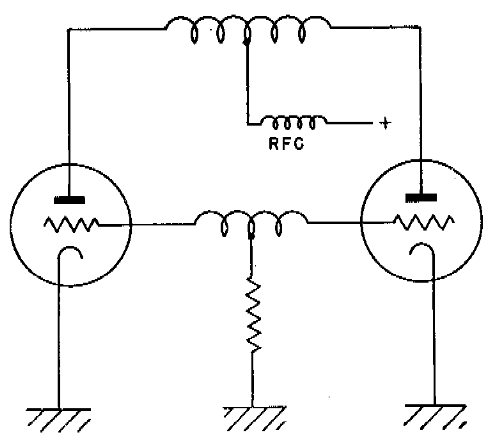


FIGURE 12. Typical push-pull Colpitts oscillator used in POD fuze circuits.

ject to spurious signals. The sources of these signals range from statistical thermal fluctua-

tions of resistance to intermittent connections. In the battery-powered fuzes, the most important noise sources were inside the triode. This electric noise can be classified as self-noise and microphonics. *Self-noise* arises without appreciable mechanical stimulus of vibration or shock. *Microphonics* refers to those noises which are mechanically induced.

The early triodes frequently were noisy (self-noise) due to the presence of charred lint. The lint had become charred in the baking operations and formed a conducting carbon filament which eventually would bridge two tube elements. The electrostatic forces on the lint were responsible for its short-circuit seeking habits. Occasionally one end of a lint piece would firmly adhere to the plate and the other to the grid, forming a miniature carbon filament incandescent lamp. In such cases, the lint would often be more luminous than the cathode. The lint problem was eliminated by improved manufacturing techniques. Another source of noise was electric leakage between leads on the outside of the glass press. This was traced to an alloying of the glass and a metallic oxide formed on the external leads in the pressing operation. There was one lead which was cut off next to the glass, since it was merely an anchor. By postponing the cutting off until after the seal was made, this wire did not get so hot and did not burn. The extra length served to conduct heat away. No more trouble was had from this source after the new procedure was established. Interelectrode leakage paths inside the envelope, i.e., on the mica spacers, can also produce noise. This phenomenon is discussed under the diode noise problem, as it was not serious in triodes.

The most difficult problem in designing the triode was the reduction of microphonic effects. In an oscillator, any variations of either the low-frequency parameters of the triode of the interelectrode capacitances produce variations of the high-frequency output and the developed grid bias. The microphony problem became acute with the transition from battery power to generator power, because the rotating system associated with the generator necessarily produces vibration. In fact, as the missile changes speed, so does the rotating system, and the frequency of the mechanical vibrations is apt to sweep across some resonant frequency of the tube structure.

The most serious resonance was that of the electrode assembly as a cantilever spring. Furthermore, if the elements are not tightly coupled at the free end, the plate can vibrate relative to the grid and filament. If the mica spacer is sufficiently snug to prevent this, then the whole assembly is a stiffer cantilever but can still vibrate with respect to the surroundings. Of course, the bending of the structure will also introduce a small relative motion between grid and anode. Microphony of this type was practically eliminated by pressing the glass envelope in against the mica spacers on both sides. This is referred to as crimping. Since the electrode support posts lie along the major diameter of the cross section of the triode, crimping of the flat sides of the bulb (preventing motion along the minor diameter) greatly increases the rigidity of the structure. This construction was adopted as standard in the NR-3A triode and was also introduced into the diodes as a general precaution, although the need for it in the latter case was not demonstrable. The arrows in Figure 8 point to the crimps on the triode.

The filamentary cathode itself cannot be made rigid. Its resonance frequencies are kept well above the audio range by proper tension, but freak low-frequency disturbances can be generated. These apparently arise from the nonlinear phenomena associated with finite vibration amplitudes of the filament. If the frequency of the driving force applied to the filament is slowly varied, the resulting vibration amplitude increases according to a normal resonance curve as the filament resonant frequency is approached. As the amplitude increases, the resonance frequency is changed by virtue of the finite amplitude. When the driving frequency passes the moving resonance, the resulting decrease of amplitude moves the resonance back, further decreasing the amplitude. The net result is a sudden drop of amplitude at driven frequency to the value predicted by the simple resonance curve. The sudden change of average tension excites a transient at the natural frequency which produces a beat with the

driven frequency. Thus, 100-c beat transients have been observed in a filament driven at approximately 5,000 c. The extreme sharpness of resonance of the filament allows this phenomenon to occur for slight variations in driving frequency. The details of the effect have not yet been investigated mathematically.

Another possible source of microphonics is associated with low filament tension. The filament passes through a small hole in the top mica and then runs to a tension spring. For various reasons, it is best to pull the filament against the edge of this hole by placing the spring off center. With low tension it is conceivable that under vibration or shock the filament will slip on this edge, producing noise.

Generally, high filament tension is indicated, but variations in tension adjustment can lead to filament breakage. The simple construction utilizing a cantilever spring is sensitive to production variations of spring displacement. This situation can be improved by the use of a longer cantilever. The extra length is incorporated by coiling the cantilever into a horizontal helix, with the last turn straightened out tangentially. This spring is made of ribbon. Another spring design that has been used can be readily described as two such springs of wire, one left-handed and one right-handed, joined by a cantilever hairpin for the filament support. This type of construction is referred to as the mousetrap spring and was not used in the NR-3 triodes because it was believed it would make the tubes too rugged.

The electrode structure must be rugged to withstand rough handling of the fuze as well as the high accelerations encountered in mortar and shell firing. Ruggedness is a simple matter of structure design, the problems arising in making a sufficiently rugged assembly as simply and cheaply as possible, and of such design as to be readily adaptable to the mass production techniques of tube construction. The filamentary cathode is the only element which cannot be braced and solidly supported, but its mass is very low. Its ruggedness is increased by shortening it, since its total mass is thus reduced, but its tensile strength is unaffected.

DIODES

The major requirements on the diode detector were small size, low filament power, and reasonably low plate resistance. The low filament power was requisite to battery-powered fuzes. With the advent of generator power, it was found advantageous to increase the diode filament ruggedness at the expense of additional heating power by increasing the filament diameter. The average characteristics of the final design, Raytheon NR-2A, are

Filament voltage	0.60 v
Filament current	70 ma
Effective plate resistance	50,000 ohms

This apparently high plate resistance is satisfactory, since the diode (see Figure 8) ordinarily works into a 1-megohm load resistance.

At high frequency, and high applied voltage, the capacitative anode-cathode current is an appreciable fraction of the normal filament current and can cause burnout. A more serious burnout problem was caused by stray inductive coupling between the oscillator and the diode filament circuit.

There have been occasional indications of diode microphony, but these have been nebulous. Crimping was adopted, as in the triode, for a general precaution. The high inverse voltage on the diode did lead to self-noise problems, involving leakage paths on the mica electrode spacer. These leakage paths could be eliminated in most cases by "sparking" the tube. This consisted of playing a high-frequency discharge over the surface of the tube, which apparently burned the conducting material off the mica. A still more effective remedy consisted of spraying the mica surface with a thin coating of Alundum. The resulting rough surface inhibits the formation of leakage paths.

The major source of leakage was found to be stray deposits of "getter" material. Redesign of the getter holder was the final step in eliminating leakage.

3.1.5 Spurious Signals and Circuit Stability

COMPONENT NOISE

Not all noise and microphony arises in the tubes. Occasionally unstable resistors and condensers are found which generate noise in op-

[redacted]

eration, but this phenomenon is not sufficiently frequent to be of concern. Most of the residual microphony can be traced to poor workmanship (or design), involving such factors as insecurely anchored connecting leads and coil windings and imperfect metallic contacts in the mechanical assembly. Insufficient restraint of the triode envelope often results in severe microphony because of the resulting variation of capacity, when the triode moves relative to its surroundings. The major part of all microphony is induced by vibration of the power-supply generator and associated rotating system. Dynamic balance of a one-piece rotating system has eliminated much of this difficulty. (See Section 4.6.)

The power supply itself can introduce noise by supplying a modulated plate voltage to the oscillator. Noise modulation of the supply voltage can arise from irregular axial motion of the generator magnet (rotor) as well as from such obvious defects of operation as rubbing of the rotor on the pole faces and intermittent rotor-stator contact via stray metallic particles. Instantaneous fluctuations of rotating speed, such as can occur through the slack of a shaft coupler, result in fluctuations of output voltage if the generator is operating on a nonconstant portion of its voltage-speed curve. Some noise has been traced to variation of contact between rectifier elements, but this is eliminated by a combination of careful element manufacture and high stack pressure.

Corona Effects

Early model oscillator-diode fuzes employed the customary series d-c load resistance on the diode rectifier. This automatically put the rectified signal on the antenna cap and isolated the cap from ground by the load resistor, normally 1 megohm. Field experience indicated that change of bomb potential in flight produced small corona effects. The high-resistance cap isolation caused the production of a signal-voltage input to the amplifier, when the charge on the bomb plus fuze was redistributed. Field effects of random function and peculiar carrier modulation could be reproduced in the laboratory under the influence of a 300-kv d-c generator.

This source of malfunction was completely eliminated by maintaining the antenna cap at the same d-c potential as the bomb. This was accomplished by grounding the cap, as far as direct current or audio is concerned, through the antenna coil and using a shunt load on the diode output. All fuzes since have incorporated the d-c grounding of the antenna. The effect of this circuit change was reported as follows:[218]

> The rearrangement of the diode coupling circuit in the ROB [abbreviation for radio-operated bomb fuze] showed satisfactory solution of the problem of eliminating operation of the fuze by static voltage discharges. With the previous arrangement, the fuze would function when placed in the neighborhood of a 30-kv field; with the new scheme, the fuze withstood visible corona and other discharges when in the neighborhood of a 300-kv field.

Unstable Oscillation

When attempts are made to increase the power output sensitivity of an oscillator, unstable oscillation conditions are frequently encountered. For example, increasing the grid leak resistance increases the bias, internal resistance, and sensitivity of the oscillator while decreasing the plate current. If the critical value of resistance is exceeded, however, the oscillator becomes unstable. This instability may be great enough to cause alternate periods of oscillation or may be mild enough to cause only a low-percentage modulation of the oscillation amplitude. The first effect is the familiar intermittent oscillation, often attributed to a large time constant in the bias circuit. The whole gamut of instabilities is incorporated into the term "squegging."

Operation under intermittent oscillation conditions offers interesting possible advantages resulting from the high ratio of peak power to average power. This was investigated to some extent in connection with battery power to reduce the average anode current. A peak voltage detector, such as the diode in the oscillator-diode fuze, can "remember" the antenna voltage from pulse to pulse, and the sensitivity with an intermittent oscillator is approximately the same as that with a steady oscillator whose amplitude is equal to the peak amplitude of the former. This type of operation is not possible in the RGD, since the rectified output is also

[redacted]

the oscillator bias. In fact, loading curves show that the RGD average bias is very insensitive when the oscillation is intermittent. Detection of target approach with the RGD might be feasible by detecting the change of intermittency period with radiation load. Experiments by A. Stratton in England (communicated verbally) show that the pulse repetition rate is a smooth sensitive function of radiation resistance. Investigation of this scheme requires the development of a variable time-delay reflection line for a dummy antenna, since for nonsteady signals the effect of target reflection cannot be replaced by an impedance. The lack of reflected signal during the first few cycles of each pulse (while the oscillation is building up) can well make a fundamental difference between field performance and loading curves representing a steady-state condition.

Just as steady oscillation would be fatal to a fuze designed to operate intermittently, squegging in any form is likely to be fatal to any fuze of the present types. It is not the intermittency itself that produces early functions, since the normal repetition rate is of the order of 100 kc and so does not affect the amplifier. Rather, it is the marginal stability of the oscillator that does the damage. For example, variation of the supply voltages can convert a steady oscillation into an intermittent one; the changeover produces transient pulses which are passed by the amplifier. Under some threshold conditions, a sensitive superregenerative operation can occur, amplifying thermal voltages and other hiss noises.

In the early unprotected RGD units, marginally high values of grid resistor occasionally produced the modulation phenomenon of the second type described above. No mention of this particular phenomenon has been found in the literature. Only a qualitative theory has been evolved.

Intermittent oscillation arises from an unstable condition in which the oscillator grid bias increases until plate current and oscillations cease. This extreme bias decays exponentially with time at a rate determined by the product of the grid-leak resistance and the bias storage capacitance. When the bias decays to a value at which oscillation will start, the oscillation starts and grows in amplitude until the bias is again too large for the tube to operate. This starting and stopping of oscillation repeats periodically.

The instability represented by the appearance of self-modulation is fundamentally of the same nature but of a lesser degree. In this case the oscillation amplitude and grid bias increase with time, but, before the tube is rendered inoperative, a temporary equilibrium between amplitude and bias is reached. Because of time lag between a change of amplitude and the resulting change of bias, this equilibrium is not stable but represents a condition where the oscillation amplitude is not sufficient to maintain the bias. Both start to decrease and continue to decrease until a lower temporary equilibrium is reached. At this low equilibrium the oscillation amplitude is more than sufficient to maintain the bias, so that the bias and amplitude again increase. The phenomenon is periodic.

Both types of instability arise because of the presence of an operating point (combination of grid bias and oscillation amplitude) that represents an unstable equilibrium. An unstable equilibrium is an equilibrium condition in which any small deviation of the operating point produces conditions that force the operating point still further from equilibrium. If no restoring force is encountered by the operating point, intermittent oscillations result. If sufficient restoring force is encountered on both sides of the unstable equilibrium point, the operating point will oscillate over a range. If the inherent instability is increased, that is, by increasing the grid leak resistance, the range of operating point variation will increase and finally intermittent oscillation will result.

The stability of the original operating point depends on the relation between oscillation amplitude and grid bias and on the time lag with which the bias variation follows a corresponding amplitude variation. An operating point is *statically* stable if a small arbitrary change of oscillation amplitude produces a greater change of bias than would be needed to keep the bias in equilibrium with the amplitude. A statically stable operating point will be *dynamically* unstable if the bias change does not occur rap-

idly enough. This dynamic instability can be produced by the use of too large a time constant in the grid-bias circuit.

The dynamic stability of the RGD oscillators has been increased by a circuit whose essential elements are shown in Figure 11. The resistor R_p in conjunction with the condenser C comprises a means of reducing dynamic instability by obtaining a voltage increment from the rate of change of amplitude and introducing this voltage increment onto the grid in such a manner as to make the bias anticipate any change of amplitude and prevent its occurrence.

The voltage drop across the stabilizing resistor R_p is proportional to the anode current. For small variations of oscillation amplitude, the anode current variation is proportional to the amplitude variation. Hence, the voltage drop across the resistor has a time rate of change proportional to the rate of change of oscillation amplitude. The terminal of this resistor nearer the anode is connected by a small capacitor to that terminal of the grid leak resistor R_g which is nearer the grid. This capacitative coupling between the stabilizing resistor and the grid leak causes an incremental voltage, which is approximately proportional to the rate of change of amplitude, to appear across the grid leak.

Static stability of an oscillator is normally achieved by the self-biasing action of a grid leak. If the amplitude of oscillation actually increases, the bias is increased, producing stability. This stabilizing circuit achieves *dynamic* stability by increasing the bias, if the oscillation amplitude *starts to increase*. Thus the bias is corrected if the amplitude has only a rate of change, without waiting for the change to actually occur. This means that if the amplitude starts to change, the grid bias anticipates the change from the fact that it started and prevents the actual change from occurring. This anticipation of a change is the antithesis of the ordinary time lag with which the bias follows an amplitude change.[127a]

Antimicrophony Circuits

The audio-frequency signal in a proximity fuze is produced by detection of a slightly modulated high-frequency oscillation. The problems of microphony are intimately associated with this low degree of modulation, which is normally about $\frac{1}{10}$ of 1 per cent. This implies that accidental variations of the steady diode voltage, oscillator bias, or plate current (according to the fuze type) need be only a fraction of a per cent in magnitude to generate spurious signals as large as normal firing signals. Highly selective amplifiers are used to discriminate against these microphonic voltages (see Section 3.2). Various schemes have been proposed to alleviate the situation, and these are all designed to neutralize essentially the steady voltage and thereby increase the fractional modulation produced by a target reflection.

In the oscillator-diode fuze, futile attempts were made to neutralize the steady high frequency applied to the diode. One such suggestion was to arrange the antenna and detector in a bridge circuit, so that the antenna load variation would appear as a bridge unbalance. No workable arrangement has been devised. Another scheme applicable only to the oscillator-diode fuze was based on the fact that oscillator microphonics produce almost identical signals on the oscillator grid bias and diode output. These can be balanced against each other in a push-pull transformer coupling arrangement. This worked in the laboratory but would not in practice because of the exacting requirements on tuning accuracy and equality of d-c grid bias and diode output.

In the RGD, where the signal appears on the oscillator bias, a simple means is available for reducing the response to plate-supply voltage variations. The grid leak may be returned to the plate supply, instead of to ground, if its resistance value is appropriately increased so that the same grid current will result in the same grid bias. This can be done for only one operating condition, since the bias is no longer proportional to the grid current. There will be a point on this resistor which will be at ground potential, since the grid end is negative and the plate end positive. Since the RGD oscillators are sufficiently linear to develop a bias proportional to the plate-supply voltages over a wide range, the cold point on the resistor will re-

[redacted]

main cold if the plate supply varies. On the other hand, variations of antenna load, which vary the bias but obviously do not affect the power supply appreciably, will generate a voltage at the initially cold point. It is apparent that this tapped resistor is a voltage divider on the signal and reduces it in the ratio $E_B/(E_g + E_B)$, where E_g is the magnitude of the bias, and E_B the plate-supply voltage. Essentially, the same results can be had for passband and higher frequencies by returning the grid to the plate supply for audio frequencies only. This eliminates possible difficulties arising from the application of positive bias while the cathode is warming up. This modification is made by using the normal ground return on the grid leak and coupling the plate supply to the amplifier input on the other side of the blocking condenser which isolates the oscillator bias from the pentode. These arrangements are satisfactory for rejection of power supply noise, when the oscillator works into a given load, such as any one missile. Installation of the fuze on a different missile generally upsets the balance, as the operating bias is different.

Another scheme has been proposed for the RGD, but not experimentally investigated. Its operation is based on the fact that a normal RGD oscillator draws a plate current which is independent of load, so that a high audio impedance in the plate circuit would not affect normal operation. If any audio voltage appearing across the impedance were properly coupled back to the grid, a high degree of degeneration (negative feedback) could be introduced for spurious signals without producing loss of sensitivity. This is possible because most spurious signals (microphones or supply fluctuations) generate in-phase variation of grid bias and plate current.

Arming Pulse

Safety of the fuze is achieved by mechanical interruption of the powder train as well as interruption of the electric circuit of the detonator. Details are discussed in Section 3.3. Necessarily, the process of arming a fuze involves completion of the detonator circuit, and this can conceivably give rise to an arming pulse which may prematurely fire the fuze.

Stray r-f currents are usually present to some extent in the power supply leads and, therefore, couple into the detonator circuit. The presence of any r-f current in the detonator, however small, indicates coupling between this circuit and the oscillator. Closure of this circuit will, therefore, change the load on the oscillator. Since the oscillator is very sensitive to load changes, a firing strength transient can occur even though the r-f current in the detonator is apparently negligible. A by-pass condenser across the detonator will not usually eliminate this pulse, but a small series choke will.

A related type of pulse occurs in mortar fuzes of the T-171 and T-132 types. In these designs, power supply and amplifier are encased in the exciting cap, so that the detonator firing current must traverse the antenna split. This requires a choke in one detonator lead; the ground return is through the antenna coil. In this arrangement, the choke does not sufficiently isolate the detonator, since the total gap potential is across the choke. Connecting the detonator is essentially the same as connecting the choke across the antenna, and it produces a strong pulse. Thorough by-pass of the detonator-switch combination would eliminate the pulse, but complete by-passing at this point is not always feasible from the production design standpoint. Circuits have been devised to immunize the fuze against this pulse and are described in later sections.

Additional Precautions

There are several problems of circuit detail that have not been discussed above, being too minor to warrant special headings. A few of these will be mentioned here as being worthy of special precaution.

The grid-bias variations are fed into the audio amplifier. The input circuits of some amplifiers can present enough shunt capacity at high frequency to cause squegging in the oscillator. A series isolation resistor of 100,000 ohms is sufficient protection. This resistor, in conjunction with grid-to-ground by-passing at the pentode, also helps to reduce stray r-f voltages on the pentode grid. Stray radio frequency at this point will be rectified, changing the bias on the pentode and hence changing the gain.

[redacted]

Stray r-f currents also reach the pentode via the filament leads. It has been found advisable to connect a fairly large capacitance, 150 to 250 μμf, across the filament supply close to the triode. These stray currents in the power leads also produce electric coupling between the oscillator and moving generator parts. Variable contact between shaft and bearings can then produce spurious signals. To minimize this effect, the plate-supply lead is also heavily bypassed to ground as it leaves the oscillator compartment.

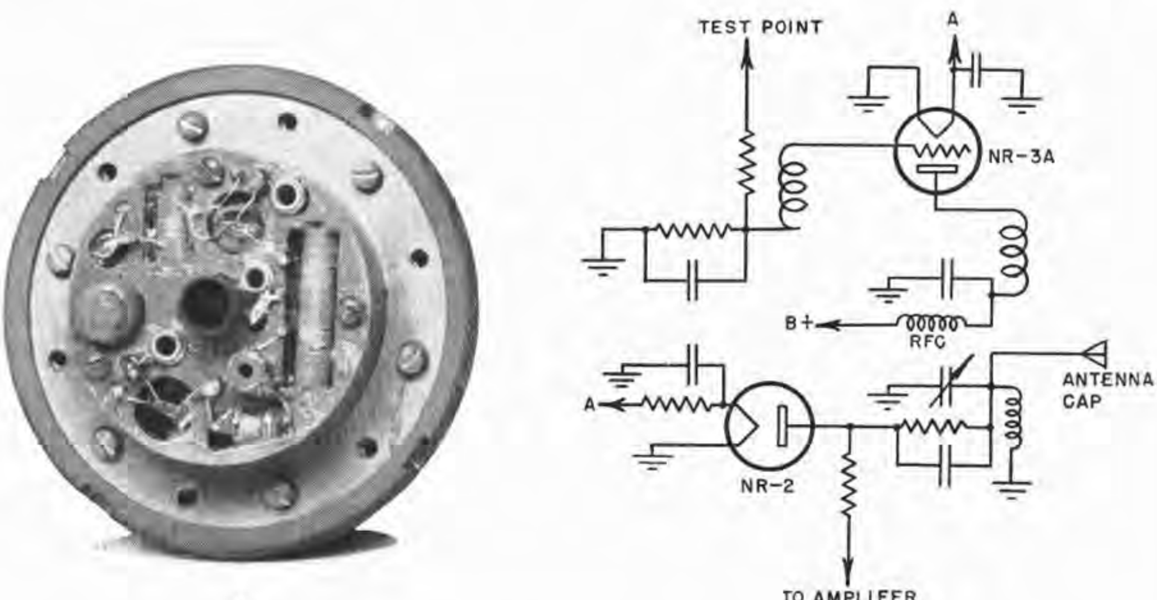
3.1.6 Typical Designs

Details of the various fuzes are presented later in the "catalog" chapter (Chapter 5). The purpose of this section will be fulfilled by presenting prototype oscillators.

The oscillator-diode type is exemplified by the T-50; the circuit is shown in Figure 13B and the component placement in Figure 13A.

The oscillator-diode circuit had several disadvantages. An obvious economic and space disadvantage is in the need for a diode and associated components. Accurate tuning of the diode-antenna circuit is a nuisance in production, and temperature and aging effects frequently detune the fuzes. The outstanding defect of this circuit is its microphony associated with frequency variation of the oscillator. Unless the diode circuit is tuned exactly, its sharp response makes it a frequency discriminator, resulting in spurious signals for any microphonic variation of triode capacitances. The RGD, on the other hand, is relatively broad in its tuning effects. That is, a given change in antenna capacity or oscillator frequency results in a change of grid bias which is very small compared to the corresponding change in diode voltage in the OD type of fuze. Detailed comparisons are presented in the bibliography.[51]

Fuzes of the RGD type require no individual oscillator adjustments and are surprisingly uniform in production. The design used in



A

B

FIGURE 13. Oscillator-diode circuit for T-50 fuze. A is photograph of oscillator block. B is circuit diagram arranged to correspond to photograph.

the T-50 series of fuzes is illustrated in Figure 14.

The dipole antenna-type fuze is illustrated by T-51. The dipole is inductively coupled to a Colpitts oscillator, the antenna coil being interwound with the oscillator coil for close coupling. Circuit and layout are shown in Figure 15.

The simplest circuit of all is that used in the T-172 mortar fuze with a single-turn loop antenna. This consists of a simple squegg-stabilized Colpitts oscillator, using the loop for the

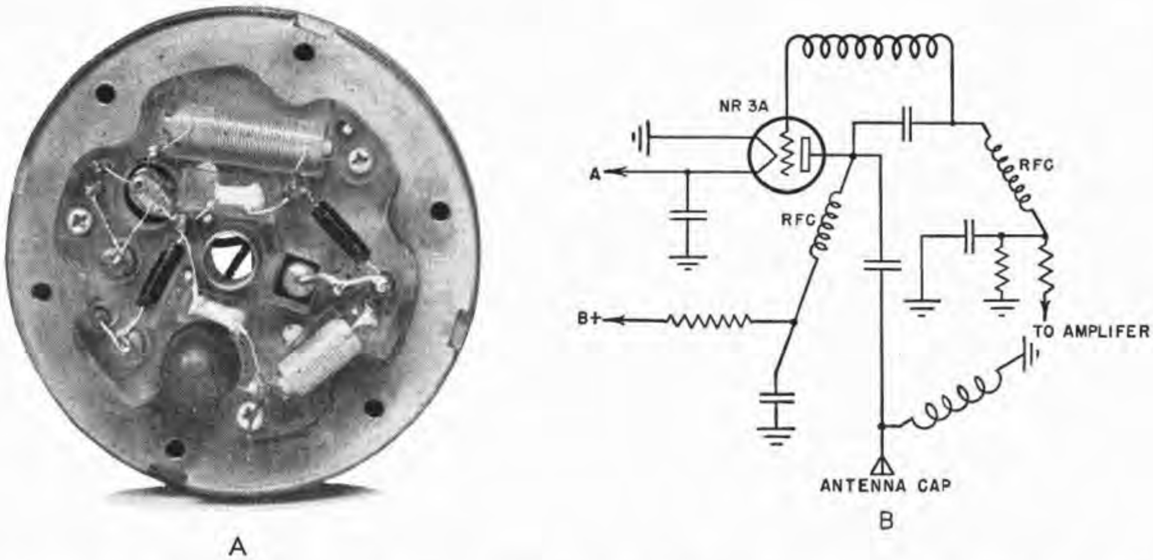


FIGURE 14. RGD circuit for T-50 fuzes. A is photograph of oscillator block. B is circuit diagram arranged to correspond to photograph.

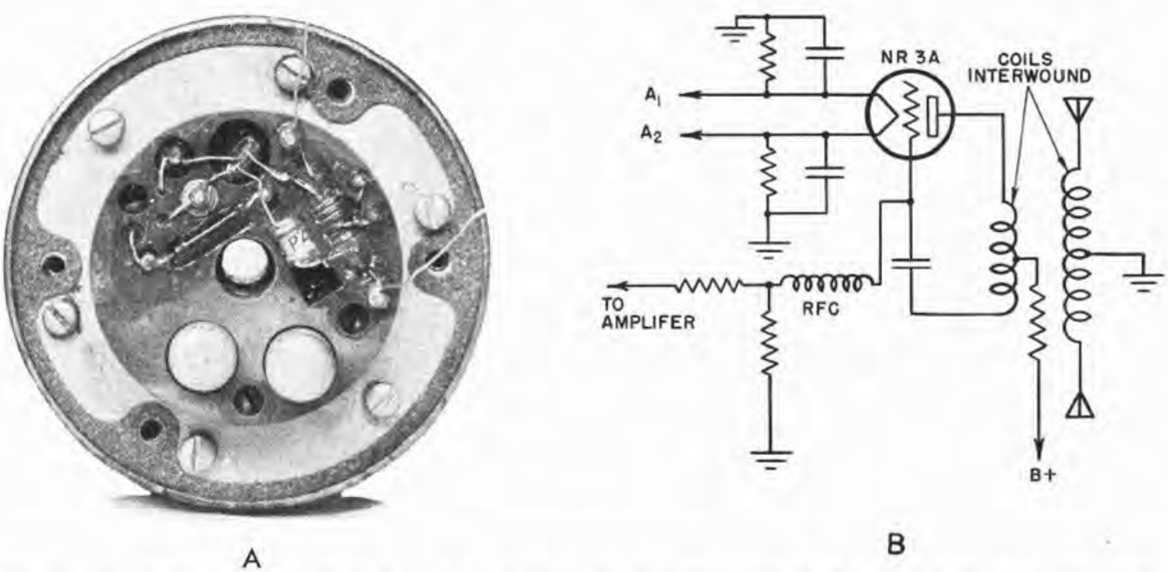


FIGURE 15. RGD circuit for T-51 fuze. A is photograph of oscillator block. B is circuit diagram arranged to correspond to photograph.

circuit inductance. The circuit is shown in Figure 16.

3.1.7 Generalization of Sensitivity Concept[d]

The sensitivity of the r-f unit has been defined as $S = R(dV/dR)$. This is sufficient for practical purposes, where the antenna circuit is operated at resonance. If, however, the antenna circuit is nonresonant or if reactance is

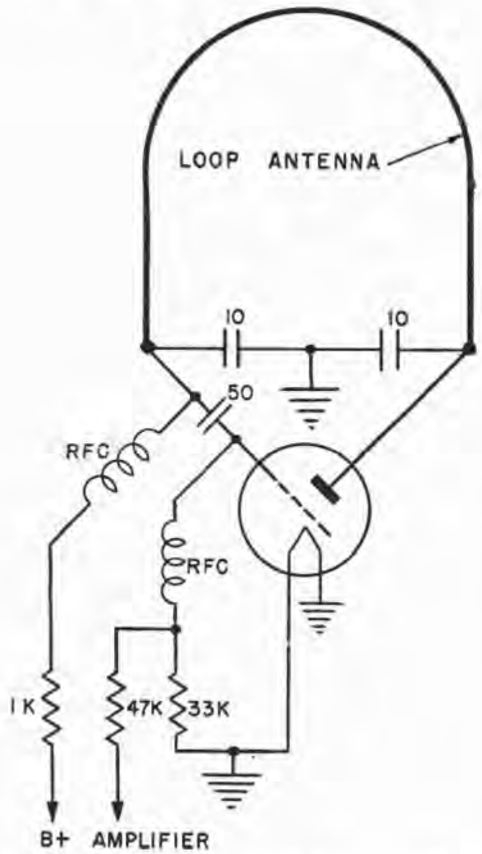


FIGURE 16. Oscillator circuit for use with loop antenna (T-172).

effectively introduced in the form of an off-frequency external signal, it is necessary to know the more complete behavior of the r-f unit.

The two-terminal equivalent of an antenna approaching a target is a fixed impedance or admittance plus a rotating additional impedance or admittance, provided the antenna does not approach the target too closely. That is, the incremental impedance or admittance produced by reflection of the antenna field changes slowly in magnitude but undergoes a continuous phase rotation (cf. Figure 1 of Chapter 2). Under the normal operating condition wherein the fixed portion of the antenna impedance is real (resistive), the maximum and minimum values of instantaneous detector voltage correspond to phase angles of 0 and 180 degrees for the incremental impedance. The complete complex detector sensitivity to impedance changes then reduces to a pure resistance sensitivity for computing the magnitude of the audio-voltage output.

The complete sensitivity could be expressed in terms of either impedance or admittance. The admittance evaluation is more convenient, since combinations of resistance and reactance can readily be placed across the fuze antenna terminals in parallel with any antenna impedance that may be present, whereas it is not feasible experimentally to insert impedance elements in series with the antenna. Dealing with admittances thus leads to an automatic ignoring of the inherent shunt capacity from the fuze cap to fuze ground.

If we write the antenna admittance as $A = C - jB$, then the detector voltage will be a function of both C and B. The term C is, of course, the reciprocal of the parallel resistance R in the formula $S = R(dV/dR)$. Therefore

$$V = V(C,B),$$

$$dV = \frac{\partial V}{\partial C}\,dC + \frac{\partial V}{\partial B}\,dB. \qquad (17)$$

The physical condition that the incremental admittance is a rotating vector requires

$$dC = |dC| \cos\theta,$$

$$dB = |dC| \sin\theta,$$

so that

$$C\frac{dV}{|dC|} = C\,\frac{\partial V}{\partial C}\cos\theta + C\,\frac{\partial V}{\partial B}\sin\theta, \qquad (18)$$

indicating that dV is a sinusoidal voltage increment. We require its magnitude.

$$C\left|\frac{dV}{dC}\right| = \sqrt{\left(C\,\frac{\partial V}{\partial C}\right)^2 + \left(C\,\frac{\partial V}{\partial B}\right)^2}. \qquad (19)$$

[d] This section may be considered as appendix material to Section 3.1.2.

We so define these terms as to make the equation read

$$S = C\left|\frac{dV}{dC}\right| = \sqrt{S_C^2 + S_B^2}, \tag{20}$$

so that the complete sensitivity is given by the quadrature addition of the conductance sensitivity S_C and the susceptance sensitivity S_B.

We immediately note that

$$S_C = C\frac{\partial V}{\partial C} = \frac{1}{R}\frac{\partial V}{\partial(1/R)} = -R\frac{\partial V}{\partial R} = -S_R, \tag{21}$$

so that our former simplified definition is preserved when the susceptance (or reactance) sensitivity vanishes.

Both quantities S_C and S_B are readily measured in the laboratory as slopes of detector voltage versus values of antenna shunts.

There is one direct application of this formula of interest to this section. It gives the solution to the question of the effect of antenna circuit detuning on sensitivity, a question of practical significance in oscillator-diode fuzes.

Consider the fuze as a constant-current generator feeding the tuned diode-antenna circuit, with internal admittance $A_i = C_i - jB_i$. Then the r-f voltage developed will be

$$E = \frac{I}{[(C_i + C) - j(B_i + B)]}, \tag{22}$$

and the diode will yield a detector voltage proportional to the magnitude of E_i,

$$V = kI[(C_i + C)^2 + (B_i + B)^2]^{-\frac{1}{2}}. \tag{23}$$

When the fuze is properly tuned (maximum detector voltage) we have

$$V = kI(C + C_i)^{-1},$$

$$C\frac{\partial V}{\partial C} = \frac{-kIC}{(C + C_i)^2} = -\frac{CV^2}{kI} = -V\left(1 - \frac{V}{V_0}\right), \tag{24}$$

where V_0 is the value of V when $C = 0$, i.e., the idling voltage. This is our original sensitivity formula, except for the trivial change of sign.

If the fuze is detuned,

$$V = kI\,[(C + C_i)^2 + (B + B_i)^2]^{-\frac{1}{2}},$$

$$C\frac{\partial V}{\partial C} = -kIC(C + C_i)\,[(C + C_i)^2 + (B + B_i)^2]^{-3/2},$$

$$= \frac{-C(C + C_i)V^3}{(kI)^2} = S_D, \tag{25}$$

where S_D represents the sensitivity when the fuze is detuned. We already have for the tuned sensitivity

$$S_T = -\frac{CV_T^2}{kI}, \tag{26}$$

in terms of the tuned voltage. Thus the ratio

$$\frac{S_D}{S_T} = \frac{C + C_i}{kI}\frac{V^3}{V_T^2} = \frac{V^3}{V_T^3}, \tag{27}$$

shows that the sensitivity falls off with detuning as the cube of the voltage.

But if the voltage has been decreased by making $B + B_i \neq 0$, then the response to variations in B must be taken into account. We must compute the complete sensitivity

$$S = \sqrt{S_C^2 + S_B^2}. \tag{28}$$

Now

$$S_B = C\frac{\partial V}{\partial B} = -kIC(B + B_i)\cdot[(C + C_i)^2 + (B + B_i)^2]^{-3/2}$$

$$= -\frac{C(B + B_i)\,V^3}{(kI)^2}, \tag{29}$$

and

$$S = \sqrt{S_B^2 + S_C^2} = \sqrt{S_B^2 + S_D^2}$$

$$= \frac{V^3C}{(kI)^2}\sqrt{(B + B_i)^2 + (C + C_i)^2} = \frac{V^2C}{kI}, \tag{30}$$

to be compared with

$$S_T = \frac{V_T^2C}{kI}, \tag{31}$$

yielding

$$\frac{S}{S_T} = \frac{V^2}{V_T^2}, \tag{32}$$

so that actually detuning drops the sensitivity only as the square of the voltage and not as the cube. This is important in setting specification limits on the accuracy of tuning in production.

3.2 AMPLIFIER SYSTEMS[e]

3.2.1 General Requirements

The amplifier receives the signals from the r-f section of the fuze and is required so to modify them that the desired signal will operate

[e] This section was prepared by Bertrand J. Miller, Ordnance Development Division of the National Bureau of Standards.

[redacted]

the thyratron at the appropriate time and place. Since the amplifier input signal consists of several components (desired signal due to reflection from target, noise due to tube and circuit vibrations, hum due to a-c filament operation and imperfect filtering of *B* supply voltage, etc.), these modifications consist of the following changes.

Amplification of the Desired Signal. In most applications, the signal generated by the r-f section is small compared to variations in striking voltage (critical bias) of the thyratrons, due to tolerances in manufacture, variations in supply voltages, temperature and other operating conditions. The amount of amplification required is different for fuzes for different applications and different for different trajectories encountered with the same application. Thus fuzes for different purposes require different amplifiers. The variation with trajectory usually imposes a requirement on the shaping of a certain sector of the gain-frequency curve of the amplifier, since the different trajectories are generally characterized by different signal frequencies at the desired point of operation. The maximum voltage gain required in the fuzes developed by Division 4 has usually been of the order of 150 times; the frequency region containing the desired signals has been between 50 and 350 c.

Attenuation of Undesired Signals. The most prominent signals, aside from those due to presence of the target, are microphonic noise and hum due to a-c operation. The latter, of course, consists of an approximately sinusoidal signal, of fundamental frequency varying from 700 c up to, in some cases, several thousand cycles. The amplitude is generally of the order of the filament supply voltage, that is, 1 to 1½ v. After sufficient refinement in oscillator tube design, the microphonic noise was also restricted to high frequencies, generally above 2,000 c. Even after all refinements of tube construction and selection processes developed to date, considerable noise in the high-frequency region can be expected. Under the severe vibration conditions encountered sharp spikes of the same order as the hum voltages can still be expected from the most carefully chosen tubes.

The preceding considerations impose two additional design conditions on the amplifier. In order to reject these undesired signals, which are of the order of volts, and function on the desired signal of the order of hundredths of a volt, the amplifier is required to have a sharp high-frequency cutoff. In addition, the amplifier is required to be linear up to large input voltages at high frequencies to avoid generation of voltages in the pass band by rectification of noise and hum envelope variations or by generating difference-frequency terms from two nearly equal noise or hum voltages or their harmonics. (The presence of two mechanically independent filaments in the triode oscillator made this last circumstance seem especially likely. Laboratory vibration tests showed that shock excitation of the filament resonances is very common, and that the two resonant frequencies generally differ very slightly, by an amount frequently in the signal-frequency region.) Of course, any serious overload at the always present, hum voltage frequency and magnitude would keep the amplifier permanently paralyzed and prevent amplification of signal frequencies.

Finally then, all these requirements are to be met in an amplifier which is compact, not critical either to supply voltages or to variations in component values due to manufacturing tolerances, insensitive to very wide ambient temperature and humidity conditions, both during the short time of use, and for long periods of storage, rugged enough not to generate noises of its own, under conditions of severe vibration, and in some cases capable of withstanding accelerations up to 12,000*g*.

3.2.2 Selection of Amplifier Characteristics

Three general types of amplifier characteristics are required: one for the longitudinally excited fuze for use against airborne targets, one for the longitudinally excited fuze for use against ground, and one for the transversely excited fuze for use against ground. The ruling factors and the resultant characteristics are quite different, so the three types will be discussed separately.

[redacted]

ANTIAIRCRAFT TARGET

The central problem in the case of an airborne target is the design of a fuze, usable on a variety of rockets of different physical dimensions, to produce a burst when the rocket passes approximately abeam of its target (see Section 1.3). Relative velocities between target and missile of 700 to 1,900 fps can be expected. Function near the ideal burst surface is desired out to passage distances of 70 ft or more.

The signal input to the amplifier under these conditions has been discussed in Sections 2.11.2 and 2.11.3.

The important characteristics are decrease of signal frequency from a maximum of $2V/\lambda$ (frequently called the head-on doppler frequency) to zero and an increase of signal amplitude; most of both changes take place in a limited region near the target. Thus a peaked amplifier with maximum gain somewhat below the head-on doppler frequency would tend to localize bursts in the appropriate region. Too sharp an amplifier cannot be used, since calculations show that, in the region where burst is desired, the signal frequency is changing rapidly (as high as 50 per cent change in frequency per cycle). The breadth of the amplifier required to realize much gain on such a signal would presumably make the precise location of the peak frequency less critical. The best location for the peak and the gain required were determined empirically.

The empirical studies consisted of field tests and of laboratory tests with the "drum generator" on the audio-signal simulator discussed in Section 2.12. As a result of such tests, the following factors were established:

1. For an r-f sensitivity of approximately 15 v and a fuze directivity pattern approximately like that of a half-wave dipole and a carrier frequency in the vicinity of Brown reference, the required amplifier sensitivity should be such that about 30-rms-mv input signal (at frequency of peak gain) will fire the thyratron.

2. The peak frequency can be located almost anywhere below two-thirds of the head-on doppler frequency with reasonably good burst placement. For function nearly abeam of the target rather than earlier on the trajectory (see footnote b of Chapter 1) the amplifier peak frequency equal to about one-half the head-on doppler would be optimum. One-half is a nominal value, since the head-on doppler frequency obviously varies with rocket velocity, target velocity, launching plane velocity, and relative orientations of these. The normal figure refers to the case of medium rocket velocity, equal attacking plane, and target plane velocities, and an overtaking aspect for the rocket. Any other orientation of target and rocket velocities would give a higher head-on doppler frequency, and a smaller value of the ratio of peak frequency to head-on doppler. A smaller value of this ratio would give bursts closer to the ideal surface in the overtaking aspect, but would probably be too low for the nose attack and other high relative-velocity aspects. Not much experimental information is available on this point, since most testing was done with a stationary target, and it was not possible to mock-up the head-on aspect by adding twice a combat-plane velocity to the normal rocket speed.[1]

A cutoff on the high-frequency side at a rate which reduces the gain by a factor of 10 at one and one-half to two times peak frequency and continues on down at a slightly smaller slope was found to be fast enough, reducing the gain to approximately unity at power-supply frequencies. Adjustment of the low-frequency side of the gain curve is ordinarily made to give a half-gain width of approximately half the peak frequency. Drum generator studies (see Section 2.12) show that at this width the gain of the amplifier to the type of signal actually encountered in use is nearly the same as the steady-state gain for a sine wave of the same instantaneous frequency for frequencies in the vicinity of peak, and that objectionable delays are not encountered.

The manner in which the circuit problems incident on realization of an amplifier having the above characteristics were solved will be discussed in Section 3.2.3. Time may be taken here to point out, however, that a different solution is possible, as pointed out in an early NDRC report.[1] This solution involves using only the decreasing frequency characteristic of the signal. The signal wave form is amplified and clipped into a square wave; the duration of each cycle is then measured. Firing of the

[redacted]

thyratron is accomplished when a long enough half-cycle occurs. This attack was not pursued at that time inasmuch as it required the use of two tubes, whereas an amplifier could be designed to give reasonably good burst placement with a single pentode. Where space is available, however, the alternative solution may have other advantages which warrant further investigation of this approach.

Some study has also been made of amplifier requirements for fuzes suitable for air-to-air bombing. Here one deals with low relative velocities, and, in addition, a different orientation of relative velocities in the most important tactical case. For the rocket case, with emphasis on the overtaking aspect, the rocket velocity is along the rocket axis in a coordinate system fixed in the target. This is a fortunate situation in one respect, since this state of affairs can be simulated in field tests with a stationary target. This state of affairs does not exist in the case of bombing a formation from above. The result of the difference is a slower rate of increase of signal from the r-f section, and, in general, a displacement of the point of maximum signal away from the point on the trajectory of closest approach. Details of the computations are referred to in the bibliography;[113] no experiments were carried out by Division 4.

Ground Approach, Longitudinal Excitation

The problem here is the development of a fuze which will give substantially uniform burst heights on a variety of bombs, dropped from different altitudes and at different airplane speeds; the same fuze to be useful both for level-flight release and dive bombing if possible. In order to show the degree to which it is possible to harmonize these requirements by appropriate amplifier design, the requirements for one fuze of this type will be presented in detail.

We choose for the purpose of this illustration, the requirements for a fuze operating at 75 mc, with use on the M-30 (100-lb GP) and the M-81 (265-lb fragmentation) bombs being contemplated. This fuze is also usable on the M-66 (2,000-lb GP), and with somewhat less effectiveness, on the M-64 (500-lb GP); but here we will consider only the first two bombs.

Because of the varying degree of mismatch between oscillator impedance and radiation load, the fuze r-f section will not have the same r-f sensitivity on the two bombs; we take as representative values a sensitivity of 11 v on the M-30 and 14 v on the M-81. Further, although the variation is slight, the directivity patterns are somewhat different, due to the differences in effective electrical length; the portions of the pattern of tactical interest are shown in Figures 17 and 18.

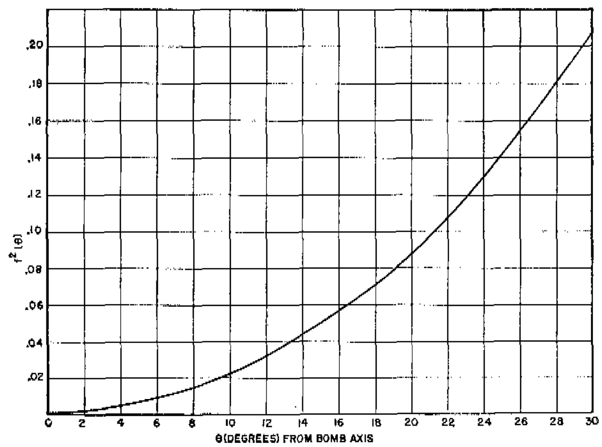


Figure 17. Directivity pattern for M-30 bomb at Brown frequency, longitudinal excitation. Curve shows detail for small angles off nose of missile.

In addition, the ballistic coefficients of the two bombs differ, so that similar release conditions result in slightly different terminal conditions (velocity and angle of approach to the ground).

Function heights of the order of 2 to 7 wavelengths will be considered; for some of these, near the nulls of the directivity pattern, it is necessary to consider the contribution of the induction field (inverse R^2 field, see Section 2.10). For this reason, function heights for nearly vertical approaches do not vary directly with amplifier gain.

Computation will be made of the amplifier gain necessary to give a function height of 50 ft over a surface with reflection coefficient equal to 0.7 for various combinations of release altitude and plane speed, both for level flight and dive bombing. The computations are made on

the basis of the theory developed in Sections 2.9 and 2.10.[101, 140]

Curves of voltage gain versus frequency required for these various conditions, based on

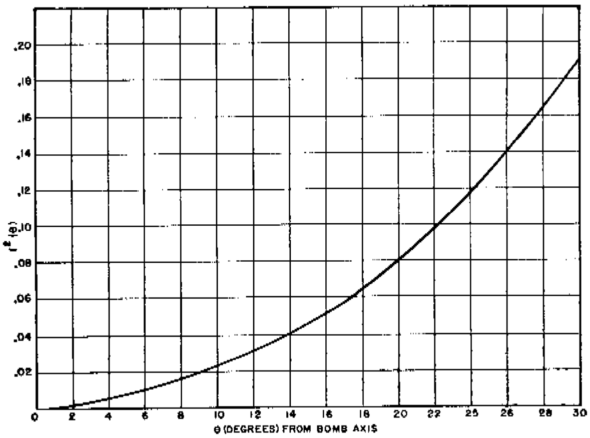


FIGURE 18. Directivity pattern for M-81 bomb, Brown frequency, longitudinal excitation. Curve shows detail for small angles off nose of missile.

an assumed holding bias of 5.3 v on the thyratron, are shown in Figure 19. The frequency ranges shown on each curve correspond to release altitudes from 2,000 to 20,000 ft for the level-flight cases, and 1,000 to 10,000 ft in the dive-bombing cases, which is assumed to contain all the range of interest. Outside these ranges, the gain should be low.

Examination of Figure 19 shows that the requirements for different release conditions are conflicting, so that a compromise is necessary. In making such a compromise, the following considerations are general:

1. The high-frequency end of each curve corresponds to a steeper angle of approach than the low-frequency end. At steeper angles the induction (inverse R^2) field is more important. Consequently, the height of function varies more nearly with the square root of gain at high frequencies than at low. This gives greater freedom of design in this region of the spectrum.

2. If an oscillator-diode type of fuze is contemplated, the tuning problem must be considered. In the case of the fuze under discussion, all production models were oscillator-diode. These were tuned on the M-30, so that the full 11-v sensitivity assumed was probably very closely realized on that bomb. Because of a slight difference in reactance of the two vehicles at the feedpoint, however, the fuze was somewhat detuned on the M-81, resulting in a reduction of the average sensitivity by about 5 per cent.

3. Very high gains should be avoided as far as possible without loss of effectiveness, since high gain obviously increases the probability of malfunction.

One compromise actually used is also shown on Figure 19, the curve being an average curve for production units (Philco T-91, type 20 amplifier). This fuze was designed in response to a request to give special weight to low-altitude

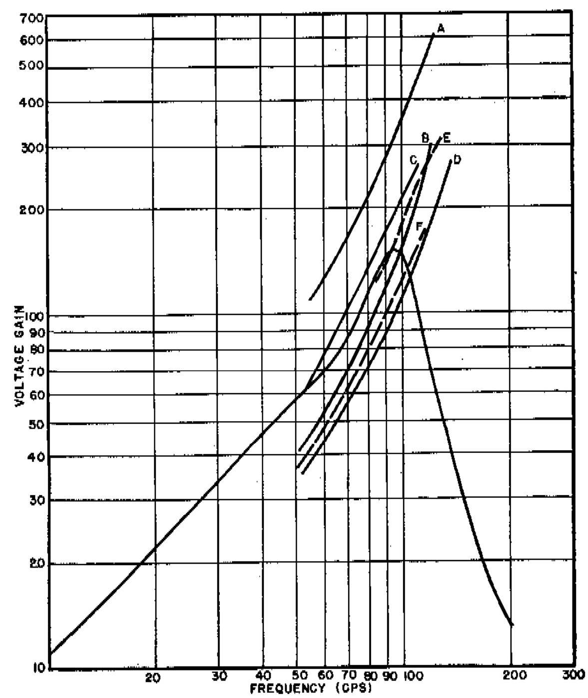


FIGURE 19. Amplifier gain curves required for longitudinally excited fuzes for different bombs in different release conditions.

The labeled curves represent conditions as follows: A, M-30 bomb released at 200 mph in level flight; B, M-30 bomb released at 300 mph at level flight; C, M-81 bomb released at 200 mph in level flight; D, M-81 bomb released at 300 mph in level flight; E, M-81 bomb released at 400 mph in 60-degree dive; F, M-81 bomb released at 300 mph in 30-degree dive. Full curve represents a compromise gain-frequency characteristic for typical unit.

and diving releases. The corresponding function heights are shown in Figure 20, for the level flight cases and in Figure 21, for the dive-bombing cases.

[redacted]

Since the input signal in this application does not change in frequency or amplitude rapidly in the region where function is desired, steady-state calculations are adequate. However, for the purpose of determining amplifier delays, more precise calculations were made, making use of Borel's theorem. According to the theorem, the response of any linear network can be computed for any form of input if one has either the network response to a unit step $H(t)$ or a sharp spike of unit impulse $H'(t)$.[54] Figure 22 shows $H(t)$ and $H'(t)$ for a typical amplifier, and Figure 23 the delays computed. The computed delays are less than 5 ft for all tactical situations for the amplifier, and are not longer for the other amplifiers employed.

For the fuzes at other frequencies, the requirements are very similar and will not be detailed here. The similarity extends even to maximum gain required, so that the changes consist primarily in frequency shifts, signal

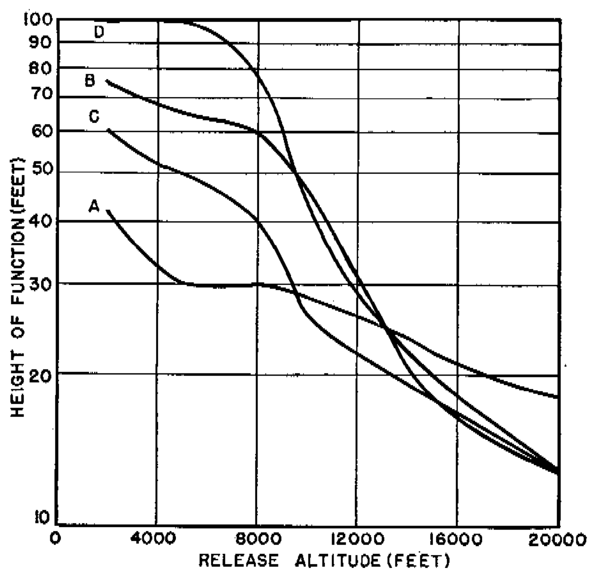


FIGURE 20. Function heights computed from gain curve of Figure 19 for level flight release. The various curves represent conditions as follows: A, M-30 bomb released at 200 mph; B, M-30 bomb released at 300 mph; C, M-81 bomb released at 200 mph; and D, M-81 bomb released at 300 mph.

frequencies being proportional to carrier frequency for bombs with similar ballistics.

The fuze for the mortar projectile using longitudinal excitation merits a brief separate discussion. Here, lower function heights are desired, of the order of 10 to 15 ft. The projectiles are much smaller than bombs and short compared to the carrier wavelengths proposed.

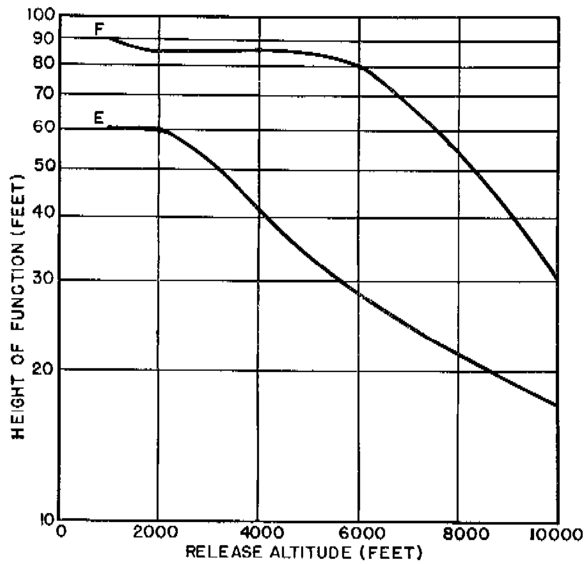


FIGURE 21. Function heights computed from gain curve of Figure 19 for dive releases. For M-81 bombs, curve E is for a 60-degree dive at 400 mph, and curve F is for a 30-degree dive at 300 mph.

As a consequence the radiation resistance is high and varies rapidly with frequency. The directivity pattern, however, is nearly independent of frequency for carrier frequencies below 135 mc. Thus for low-carrier frequency, one expects low r-f sensitivity, but this is balanced by a larger scale factor (wavelength, λ), and more important induction field contribution. (The latter is of great importance because of the low function height desired.) As a consequence of the interaction of these factors, it develops that an amplifier gain curve can be drawn which is optimum not just for one carrier frequency but for any carrier between 70 and 130 mc. It was also found possible to realize this gain-frequency curve (Figure 24) economically.[130]

GROUND APPROACH, TRANSVERSE EXCITATION

The difference between the amplifier required in the case of a transversely excited fuze and that of the longitudinally excited fuze arises

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from the difference in the directivity patterns. In the longitudinal case, one has axial symmetry about the axis of the bomb. The directivity pattern is a minimum for vertical ap-

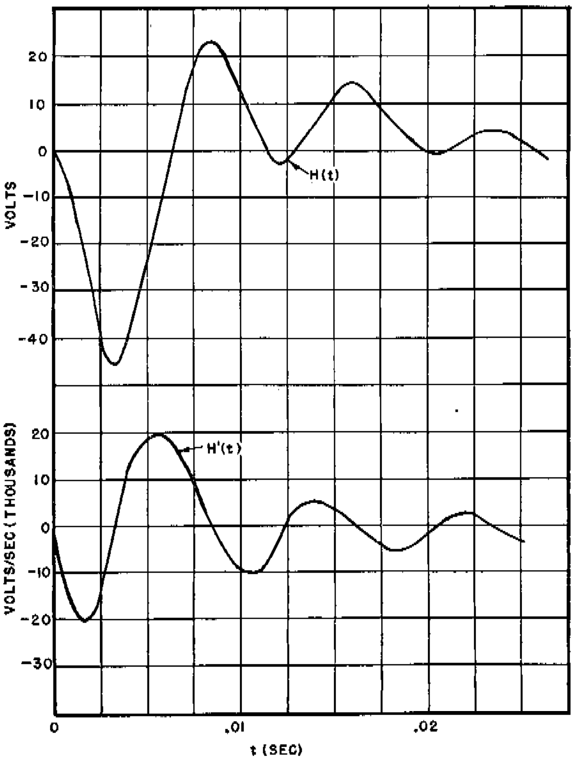

FIGURE 22. Response of typical amplifier to a unit step function, $H(t)$, and a short pulse of unit impulse, $H'(t)$.

proach, and increases rapidly as the angle of approach increases (angle between trajectory and vertical) for any orientation of the bomb about its axis.

In the case of the transversely excited fuze, the directivity pattern is maximum for vertical approach. For angles of approach other than zero, the value of the directivity pattern depends somewhat on the orientation. For most tactical situations, however, the signal strength is nearly independent of release altitude and hence of signal frequency. A relatively flat gain curve is therefore required. For the carrier frequency used (about 150 mc), and the bombs employed, the useful tactical range of altitudes gives a frequency range from 165 to 330 c.

The value of the maximum gain is determined by the r-f sensitivity at the operating load and by the directivity pattern. Because of the high radiation resistance, and consequent poor match to oscillator impedance, sensitivities are lower than those encountered on most bombs with the longitudinal fuzes. The antenna gains were approximately the same. However, the tactical range of approach angles centered near the maximum of the directivity pattern in the transverse types, instead of near the minimum, as was the case with the longitudinal types. The net effect of all these factors is a requirement for somewhat less gain (for the same height) for the transverse fuzes. Production fuzes, however, were in fact built with approximately the same maximum gain as the longi-

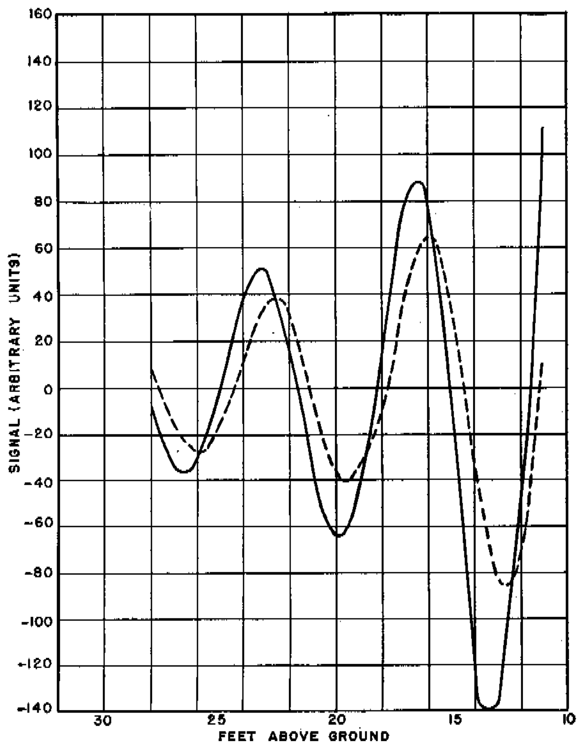

FIGURE 23. Amplifier input and output signals for various heights above ground, assuming approach of 30 degrees with the vertical and vertical velocity of 790 fps. Assumed amplifier peaked frequency is 120 c. Carrier frequency: Brown. Solid curve represents input signal multiplied by steady state gain; dashed line represents output signal (inverted).

tudinal fuzes and consequently gave somewhat greater heights of function.

This amplifier is required to have a sharper high-frequency cutoff than the amplifier for

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the longitudinal fuzes by virtue of the higher carrier frequency employed. This necessitated maintaining a high gain at 330 c, whereas the

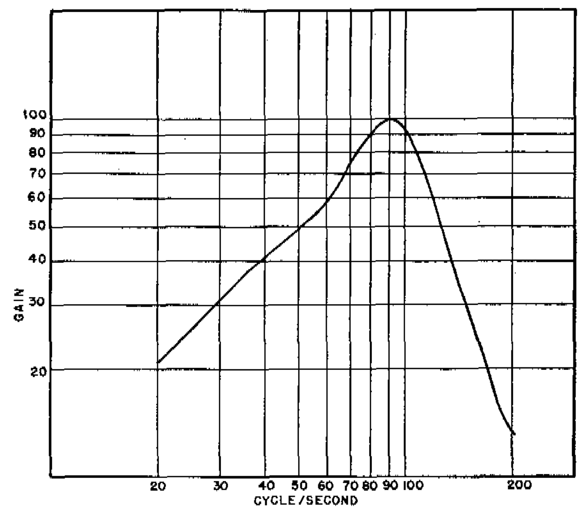

FIGURE 24. Gain-frequency characteristic curve required for trench mortar shell fuze, assuming carrier frequency compensation.

highest frequency encountered with longitudinal types was 225 c. Since power-supply frequencies at arming may be as low as 700 c, a very rapid cutoff is required.

3.2.3 Methods of Securing Required Gain and Shaping; Typical Circuits

AXIAL ANTENNA FUZES

All amplifiers used in modern fuzes for nonrotating missiles are lineal descendants of the amplifier developed for the MC-382, the electronic control part of the T-5 or T-6 fuzes. Here the shaping was accomplished by a feedback network similar to that employed in RC oscillators, using only resistors and condensers. With a network employing three series condenser-shunt resistor sections between grid and plate of single tube amplifiers, the following relations are noted:

1. At low frequencies, the feedback amplitude is very small and phase shift is nearly 270 degrees.
2. At higher frequencies, feedback amplitude is larger and phase shift through network is in the vicinity of 180 degrees; this constitutes regenerative feedback.
3. At still higher frequencies, feedback amplitude is still larger and phase shift approaches zero, i.e., the amplifier becomes highly degenerate.

This principle is attractive because it gives promise of providing a sharp high-frequency cutoff, together with large voltage-handling capacity in the high-frequency region, with the consequent freedom from cross modulation of large noise voltages. Consequently, the circuit was developed and used in the form shown in Figure 25, employing pentodes developed from hearing-aid tubes.

One peculiarity of this circuit is perhaps sufficiently basic to warrant discussion here. The resistances R_g, R_7, and the parallel combination of R_6 and the source impedance, constitute a voltage divider which controls the amount of feedback. Since R_6 is of the order of megohms, and the impedance of the r-f section as an audio generator is of the order of tens of kilo ohms, it is evident that the amplifier characteristics depend markedly on the impedance of the source. Thus all amplifiers of this family required properly designed test circuits (see Chapter 7) which simulated the impedance

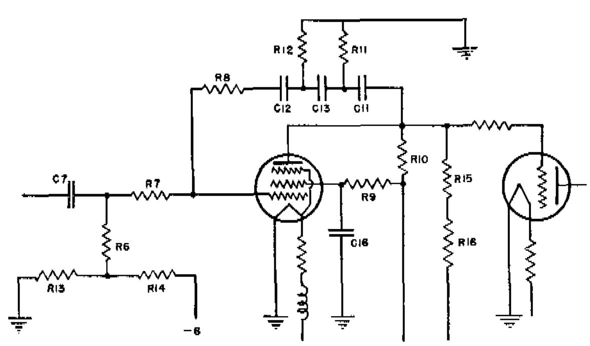

FIGURE 25. Schematic circuit of feedback amplifier employed in T-5, T-6 fuzes.

of the sources for which the amplifiers were designed. Similarly, some restrictions were imposed on source design, since the amplifier presented to the source an impedance varied radically with frequency, even becoming negative in certain cases.

The values used in this circuit will not be cited as typical examples, despite the historic interest of the circuit, for two reasons. First, the circuit was the last designed for battery

[redacted]

operation; the high-frequency cutoff was inadequate for generator use with raw alternating current as a filament supply. Second, because of the status of tube development at the time, many of the values represented compromises. Tube development and circuit development were proceeding simultaneously. At the time epoch corresponding to Figure 25, two reasonably satisfactory but different pentodes had been developed by different laboratories. The divergence in characteristics, however, was not so large that using both in the same amplifier was not feasible, by some judicious compromising on values.

A more typical amplifier, therefore, is shown in Figure 26. This is a type furnishing a gain-frequency curve of shape suitable either for airborne targets or for ground approach, with longitudinal excitation. It will be noted that the feedback voltage is now divided by a capacity, rather than a resistance divider; at frequencies above peak frequency, this provides capacity loading on the input grid and improves the high-frequency cutoff. Further high-frequency attenuation is provided by the series

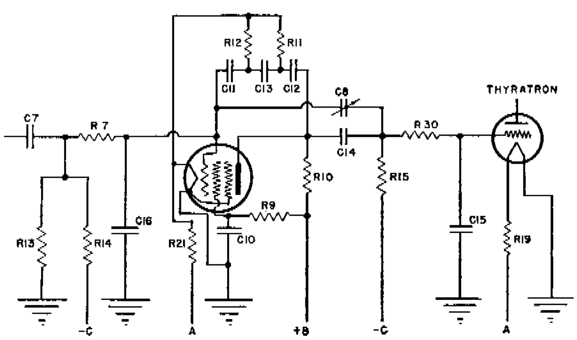

FIGURE 26. Later feedback amplifier circuit employed in generator-powered fuzes. Feedback circuit shown employs a feedback divider (C_{11}, C_{16}) and gain control (C_8).

R-shunt C network in the thyratron grid circuit. A higher gain level was sought and was obtained in part by increasing the feedback. This additional gain necessitated the provision of a feedback adjustment. A variable capacity C was provided for this purpose. The feedback network is designed to give too much feedback, so that gains are too high; adjustment of C introduces a controllable amount of degeneration. This scheme was adopted because it proved to be possible in this way to control peak gain with only minor effects on the frequency at which peak gain was realized.

A typical gain-frequency curve is reproduced as Figure 27; also shown is the curve noted when the pentode grid side of both feedback loops is disconnected. It will be noted that the gain at peak frequency is multiplied by a factor of about 2.5 by the feedback; this is about the maximum amount of feedback usable if too sharp gain curves and undue dependence on variations in supply voltage are to be avoided. The gain without feedback is of course depressed by the various high-frequency attenuating networks, and by the loading of the plate circuit by the feedback loop; the same tube in a conventional RC-coupled amplifier gives a gain of about 100 times with the supply voltages indicated.

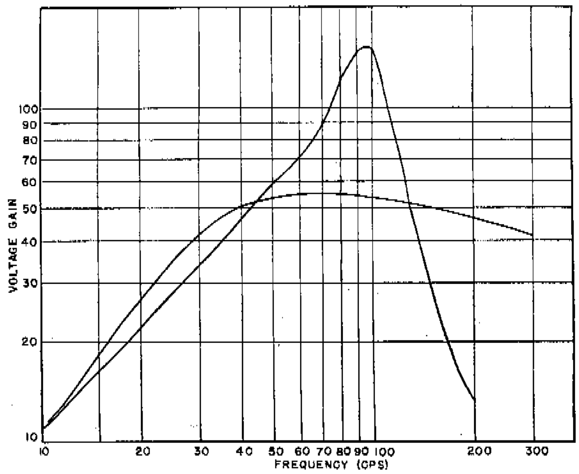

FIGURE 27. Gain-frequency characteristic and flat gain characteristic given by circuit of Figure 26.

Within reasonable limits, the amplifier can be redesigned to give the same shaping at other peak frequencies by simply scaling the capacities; this practice was largely followed here, with minor readjustment of values to commercially available ones where necessary.

A somewhat different shaping was required for mortar fuzes, because of the rather different ballistic properties and conditions of use for these projectiles; the requisite gain curve is shown in Figure 24.

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Transverse-Antenna Fuzes

The relatively high flat plateau, with steep cutoff on the high side, required of amplifiers for transverse-antenna fuzes suggests the use of two peaks. This attack on the problem has

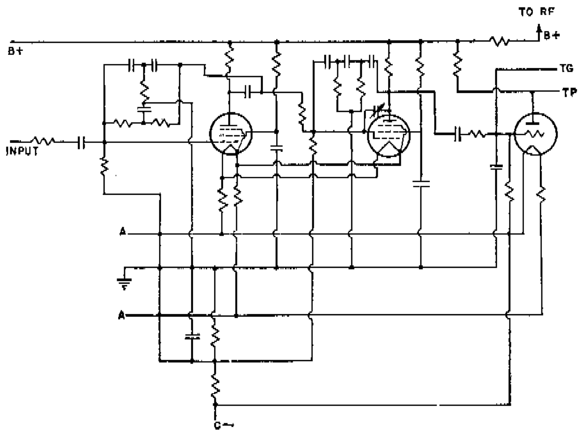

Figure 28. Two-stage feedback amplifier for use with transverse antenna fuze.

been pursued in various ways. Perhaps the most obvious is the use of two stages similar to Figure 25 in cascade, with the feedback loops adjusted to different peak frequencies. Another possibility is the use of two feedback loops in

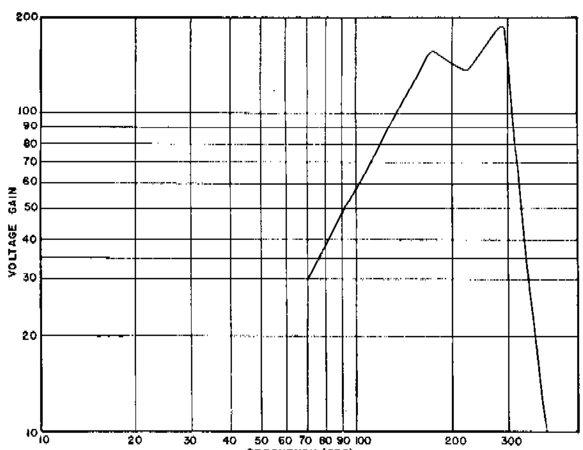

Figure 29. Gain-frequency characteristic for two-stage feedback amplifier of Figure 28.

the same stage. Here a network similar to that of Figure 25 was employed for the higher frequency peak, and a network with series resistance and shunt capacity was used for the lower frequency peak. (This order was essential since the degenerative feedback below peak frequency for the series C network was attenuated, as was that above peak-frequency for the shunt C network.) Finally, the conventional feedback network to provide the high peak, combined with an LC network for the lower-frequency peak, could be used.

All these approaches were investigated. Limited experience with the dual-feedback loop indicated a relatively high supply-voltage sensitivity; since other successful and economical solutions of the problem were available, this attack was not vigorously pressed. A typical two-stage solution is shown in Figure 28. Because of requiring two tubes, this solution found little use; however, it obviously has

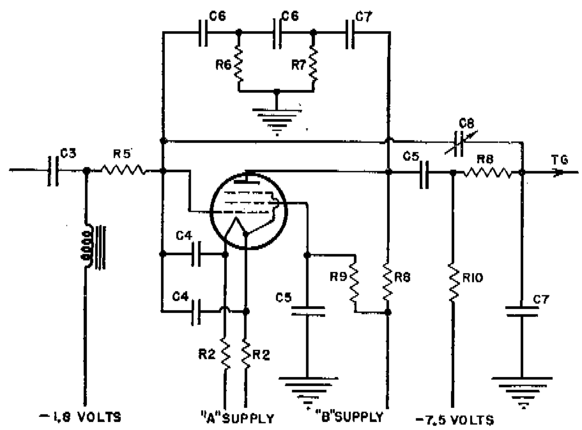

Figure 30. Schematic diagram for feedback amplifier with tuned choke input (used in T-51).

greater flexibility and, as shown in Figure 29, can provide extremely sharp cutoffs which might be necessary in some applications.

The solution of the problem which found the greatest practical use employed a series resonant LC network in the pentode grid for the low-frequency peak. The high-frequency peak was obtained by feedback; the two circuits combined to give a very fast high-frequency cutoff, necessary in this case by virtue of the proximity between signal and generator frequencies. (This same fact was responsible for the filament center tapping employed.) The feedback circuit thus still supplies the high-frequency grid degeneration which enables the amplifier to handle large high-frequency signals. The design of the feedback loop, as noted in Figure 30 is conventional; the same type of gain control is used.

The low-frequency peak is supplied by the grid choke and C_3; the Q of this resonant circuit is controlled by a series resistor. It is of interest to note that a low-impedance C bias source must be provided for in order not to broaden the resonance curve.

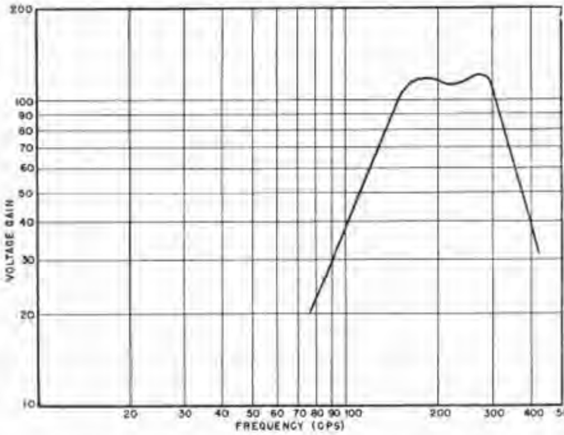

FIGURE 31. Gain-frequency characteristic for choke input feedback amplifier.

The type of M-8 head employing plate current rather than grid voltage variations was used in one bomb fuze with transverse excitation (T-82) and thus required a similar amplifier-gain curve. Figures 32 and 33 show a typical circuit and gain curve. Here, trans-

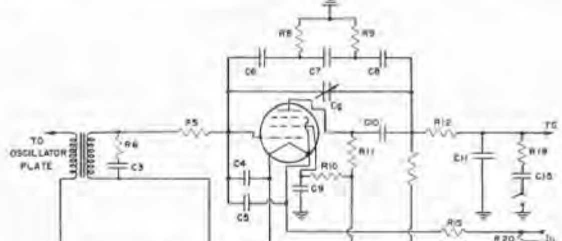

FIGURE 32. Schematic diagram for feedback amplifier with transformer input. (The switch shown below C15 is a sensitivity control.)

former input to the amplifier is employed, the low-frequency peak being supplied by resonating the transformer secondary; the usual high-frequency feedback network being employed.

COMBINATION AMPLIFIERS

The applicability of a fuze to various missiles could be increased if it were possible to vary the amplifier shaping in the field by a simple adjustment. Thus, although the same general shaping is required in a rocket fuze for ground approach and for airborne targets, the required

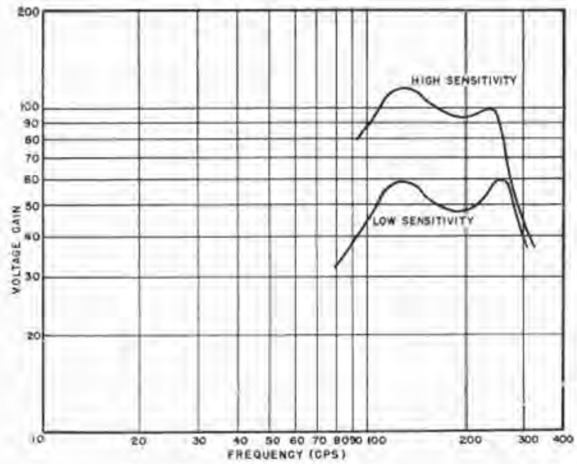

FIGURE 33. Gain-frequency characteristics of amplifier shown in Figure 32. High and low curves correspond to switch open and closed.

peak frequency and gain are different. The same remark is true if it is desired to use the same type of fuze against airborne targets on rockets and on bombs. By the introduction of shorting switches, to cut additional feedback sections in or out, good approximations to two different ideal gain curves can be provided in

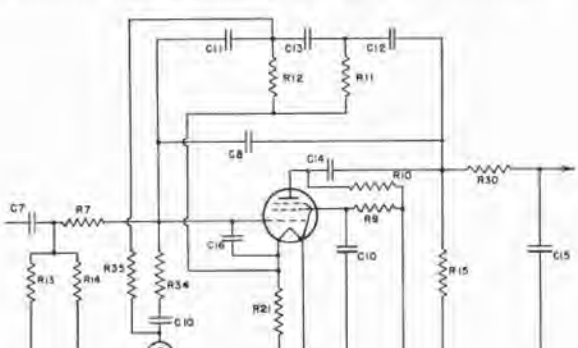

FIGURE 34. Combination amplifier for use in air-to-air and air-to-ground applications. Switch S allows transfer from one application to the other.

the same amplifier. Typical circuit and gain curves are shown in Figures 34 and 35. Since

[redacted]

operation of the switch consists in removing or inserting a screw from the chassis, the operation is readily performed in the field immediately before fuzing the projectile when the application is determined.

A similar adjustment was investigated on some transverse-type fuzes to provide sensitivity control. Removal of a screw inserts a voltage divider in the amplifier, whose effect is to halve the gain and thus halve the expected height of burst.

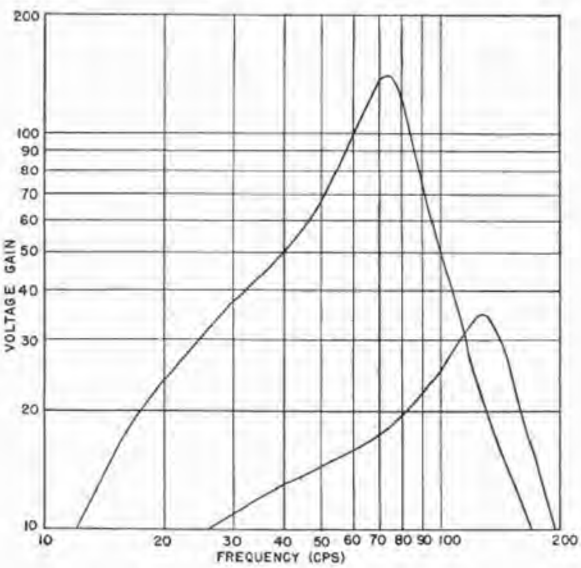

FIGURE 35. Gain-frequency characteristics for amplifier shown in Figure 34. Upper curve represents air-to-air case, the other, air-to-ground.

3.2.4 Properties of Pentodes

The electric properties of the pentodes used in the amplifiers differed in some respects according to the manufacturer of the pentode. Average values are shown in the accompanying table.

	Raytheon	Sylvania	GE_2	
R_p	2.0	1.6	1.4	megohms
g_m	218	195	176	μmhos
u	445	310	250	
$R_{\text{screen grid}}$	0.32	0.27	0.54	megohms
I_f	62	60	64	ma
Input impedance	30	10	30	megohms (measured at 60 c)

The values cited above were not measured at the same element voltages for the different tubes, but at the operating voltages occurring at those elements when the tube was operated in a typical feedback amplifier, with 1.4-v A supply, 140-v B supply, and —1.8-v C bias.

Security requirements were imposed on the mechanical properties in part. (See Section 3.1.5.) For the greater part of the time interval, including the development and tactical use of fuzes for nonrotating missiles, it was required that all tubes used *must* fail on a 20,000g centrifuge test. It proved possible to build tubes which would pass 2,500g with reasonable assurance of failure at 20,000g; accordingly, this level of ruggedness was chosen for the great majority of the tubes built for this program.

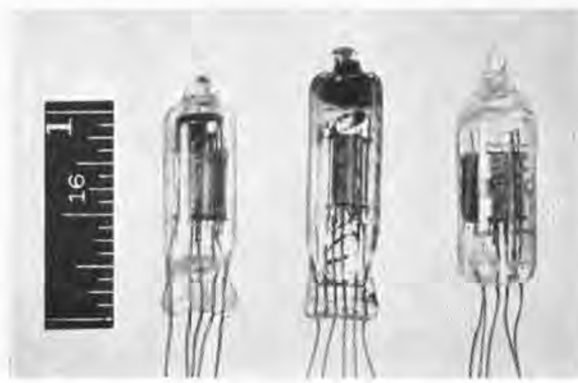

FIGURE 36. View of three pentodes used in amplifiers for proximity fuzes. These are from left to right: GE pentode, Raytheon pentode NR-5, and Sylvania NS-5 pentode.

In the latter stages of development, some missiles with launching accelerations near 10,000g were encountered. Relaxation of security requirements was secured and more rugged tubes were made by simple mechanical changes.

In favorable contrast to the oscillator triode situation, the allowable ruggedness level for the pentode proved sufficient for suppression of microphonics. Presumably because of the low voltage level at the pentode grid, microphonic audio amplifiers were exceedingly rare. In almost every case of a noisy unit, blocking of the oscillator would remove all microphonic output.

Figure 36 shows the external appearance of pentodes of different manufacturers; Figure 37 shows the internal construction of a typical pentode.

For further details reference should be made to the final reports of the tube manufacturers.[201, 202]

3.2.5 Adjustment and Testing

With components of commercial tolerances, it was found possible to build the amplifiers with only one adjustable component; the inverse feedback condenser, shown, for example, as C_8 in Figure 26. This condenser controlled the peak gain primarily, with only second-order effects on the peak frequency. In some of the double-peaked amplifiers, an additional adjustment was provided in the form of a resistor controlling the Q of the series resonant circuit responsible for the low-frequency peak.

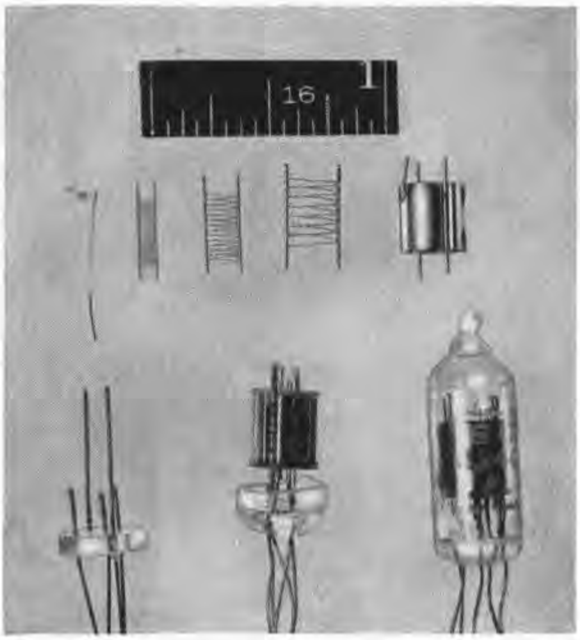

FIGURE 27. View of NS-5 pentode with envelope removed, showing various components.

Testing is described in greater detail in Chapter 7. Two properties of the signal injection circuit were critical: the impedance and the hum level. The impedance of the synthetic signal source had to be the same as the actual source, since, as was pointed out earlier, this impedance is a portion of the feedback voltage dividing network. In addition, hum, or a signal of power-supply frequency, had to be injected along with the desired signal to simulate actual operating conditions. This was because millivolts required to fire the thyratron were measured rather than voltage gain, since the former were of more direct applicability. The effective critical bias on the thyratron, however, depended on the amount and phase of hum voltage passed through the amplifier. Special signal injection circuits were consequently designed for each amplifier.

Where gain was measured, the output voltage was defined as that appearing on the thyratron grid. In virtue of the feedback applied to the amplifier and also of the high-frequency attenuating network preceding the thyratron grid, the impedance level at this point was very high. This necessitated the use of very high-impedance voltmeters for the measurement of output voltage.

3.2.6 Response to Spurious Signals

Spurious signals are here defined as any signals due to causes other than motion with respect to a reflector. Since these latter are always expected in a relatively restricted region of the frequency spectrum, the first precaution is evidently to keep amplifier gain low outside this region. Certain transients however are of sufficient magnitude to require separate consideration.

The rocket fuzes for antiaircraft use generally were required to be ready for operation in a period ranging from ½ sec to slightly more than 1 sec. During this period, the d-c level at the amplifier input changes from 0 to approximately -40 v; filament voltage is applied suddenly to all tubes and plate voltage to all, although not simultaneously; the application of plate voltage to the thyratron is delayed. Firing during this cycle is prevented by maintaining the following sequence.

1. Plate and filament voltage to oscillator, diode (if any), pentode, and filament voltage for the thyratron are applied. Since the pentode filament is not yet emitting, its plate assumes the potential of the supply voltage and a positive pulse appears on the thyratron grid. Since

the thyratron filament is also cold and its plate circuit is open, firing does not occur.

2. The properties of the pentode and oscillator (and diode, if any) filaments, and the voltages supplied to them, are so adjusted that the oscillator (or oscillator and diode) warm up *before* the pentode. Thus when the pentode begins to warm up, the tube is at first cut off by the negative surge on its input. Pentode warm-up is substantially complete before this negative charge leaks off via the grid leak, resulting in a smooth drop of the pentode plate to its operating point. Thus, during the time the thyratron is warming up, a negative signal is appearing on its grid.

3. The only possible transients due to sudden application of thyratron plate voltage are the signals due to thyratron plate-grid capacitance, and any signals due to switch action in leakage r-f fields from the oscillator. The first is suppressed by the large capacity from thyratron grid to ground. The second is suppressed by associating chokes and capacities with the switch in the appropriate fashion. Since leakage fields are small, switch-oscillator coupling is not strong and circuit design is not critical. (See Section 3.3.)

A somewhat different problem occurs in the case of mortar fuzes. These are sometimes fired at very high angles, so that velocities are low near the peak of the trajectory. At the consequent low generator speeds and supply voltages, the oscillator plate current will be reduced; since plate current is a large factor in determining C bias, the thyratron bias will be reduced. Additionally, the supply-voltage rise with increasing speed on the downward leg of the trajectory will be very rapid and may give rise to transients within the amplifier itself resulting in positive signals on the thyratron grid.

Since thyratron plate voltage is also low at low speeds, some reduction in C bias can be tolerated. A shunt load on the B supply can be used which will draw enough current through the bias resistor to hold the thyratron at low-plate voltages.

The only transient on the downward leg of the trajectory which gave positive thyratron-grid signals was found to be associated with the pentode screen-grid circuit. The problem was solved by supplying the screen from a voltage divider, in place of a simple series dropping resistor. Because of the differing screen impedances of tubes of different make, a different divider was used for each tube manufacturer.

As in the rocket fuze, any transients due to the oscillator dropping out of oscillation and starting up again were handled by the shorter warm-up time of the oscillator filament, compared to pentode and thyratron filaments. Where necessary, this difference was accentuated by series resistors in pentode and thyratron filament circuits.

It is of interest to note the rapidity of warm-up achieved with the tubes at hand; the MC-382, for example, was completely stabilized and ready for arming (application of thyratron plate voltage) in less than 0.25 sec after the application of oscillator and amplifier supply voltage.

3.2.7 Tolerance of Components and Variation in Performance

Exhaustive studies of the effects of variations in the component values were conducted. In general, the conclusion reached was that satisfactory restriction of performance variations could be achieved in the single-peak amplifiers by the use of unselected components of 10 per cent tolerance. (In the double peak amplifiers, 5 per cent components were used in the feedback network.) By the use of sorting (pairing high capacities and low resistors, or vice versa) 20 per cent components could be used in most places.

Except for a few small resistors (as in filament circuits), carbon resistors and paper condensers were employed. The temperature coefficients are opposite but that of the resistors dominates, so that the amplifier has a negative gain-temperature coefficient. The value depends largely on the form of the gain-control condenser, ranging from −0.7 per cent per degree centigrade with one form (twisted pair of wires) to −0.2 per cent per degree centigrade with another (ceramic condenser).

The supply voltage sensitivity was not so large as might be expected from a regenerative circuit; percentage gain changes were approximately equal to percentage supply-voltage changes.

Because of the many high-impedance points in the amplifiers, good protection against moisture was required, including "built-in" moisture as well as any encountered in subsequent exposures to humid atmospheres. The impedance between pentode grid and plate was particularly high; this necessitated specifying better than common practice in tube washing to eliminate any conducting salts or acids on the tube press. The assembled amplifier was given a dip in hot wax to drive out as much moisture as possible and seal it out, after which the assembly was potted. Tung oil and Glidden potting compounds were used. (See Section 4.7.)

Figure 38 shows the variations encountered from all causes in one type of amplifier, except supply voltages, which were standardized. Temperature, of course, was not standardized, but the range of variation was limited.

3.3 THE DETONATOR CIRCUIT[f]

3.3.1 General Requirements

The purpose of any fuze is to initiate the high-velocity shock wave needed to set off the explosive charge. In the proximity fuze, an electric detonator is used to link together the operating parts of the fuze and the powder train which sets off the high explosive. The detonator assembly must meet the stringent safety requirements of the Armed Forces, and, for proper functioning, the detonator imposes even more stringent requirements on the electric firing network. The detonator is fired by the discharge through its bridge wire of the energy stored on a large capacitor. A screen-grid thyratron is used as the electronic switch to discharge the capacitor through the detonator. The thyratron holding bias is set so that the tube will fire when the fuze receives a signal larger than the predetermined threshold for functioning. In order that the fuze will not function prematurely, both electric and mechanical methods are used to make the fuze entirely inoperable before arming. Before electric arming occurs the detonator bridge wire is not connected to the electric circuit, so that no current can flow through it, regardless of what happens to the rest of the fuze. Further, in the generator-powered fuzes no power is available

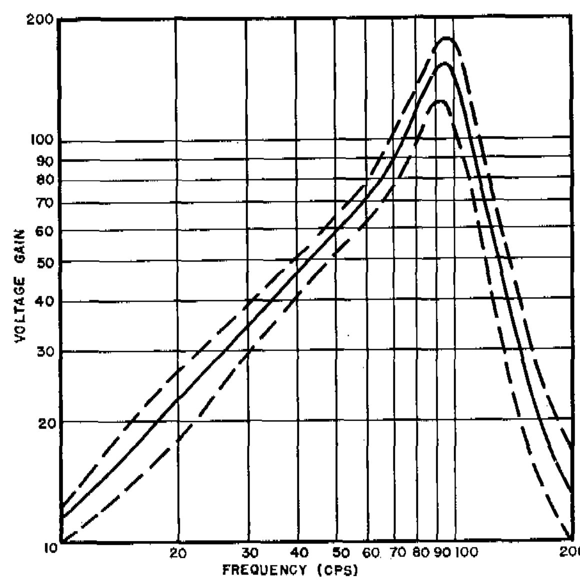

FIGURE 38. Variations of gain encountered in feedback amplifier. Voltages were held constant and gain curves translated to common peak frequency. Dotted curves represent limits within which are included characteristics of approximately ⅔ of the amplifiers.

until the fuze is traveling through the air at a speed greater than 80 mph (see Section 3.4). As an additional protection, before mechanical arming, a ¼-in. thick brass plate is located between the detonator and the tetryl powder train (see Chapter 4). Thus, even if the detonator explodes, the resultant shock wave, after passing through the brass plate, will not be large enough to set off the tetryl.

It is obvious that the detonator itself must be so located that the shock wave due to its detonation will set off the tetryl booster charge. This limitation permits either the end or a side of the metal cup to face the tetryl. It is not so

[f] This section was prepared by Charles Ravitsky of the Ordnance Development Division of the National Bureau of Standards. Mahlon F. Peck of the same organization prepared Section 3.3.4 on the properties of the thyratron. Major bibliographical references for this section are 6, 8, 25, 57, and 58.

obvious, however, that the electric components of the detonator circuit must be so arranged that stray coupling to the other electric networks is minimized. It was found that inadequate shielding of the detonator circuit sometimes caused early functioning of the fuze due to transients set up at the time of arming. In order to eliminate the detrimental effect of transients when the detonator was connected to the circuit at arming, r-f chokes were put in series with the detonator, and a condenser was used to by-pass it at radio frequencies (compare with Section 3.1.5).

The principal components of the detonator circuit are the electric detonator, the condenser, and the thyratron (Figure 39). In addition, the impedance of the filament power supply is in series with one leg of the thyratron filament in some of the fuzes, and half the impedance is in series with each leg of the thyratron filament in

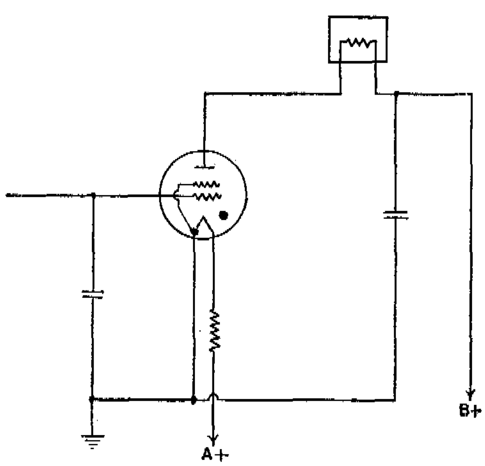

FIGURE 39. Elementary detonator circuit.

other fuzes. Also, in some of the fuzes there is an r-f choke[172] in series with each of the detonator leads and a small condenser in parallel with the detonator. These additional components have only a minor effect on the proper operation of the detonator circuit and were added to reduce transients at arming. A small resistor of 3 or 5 ohms is included in series with the ungrounded end of the thyratron filament in order to decrease the filament current to the value for which the filament was designed.

This section of the report will deal with the major components of the detonator circuit. As the other components do not appreciably influence the action of the circuit, they can be disposed of here in only a few words. The filament resistance is a commercial $\frac{1}{4}$-w resistor. The r-f choke in series with the detonator is the same as those used in the oscillator section of the fuze. It consists of 78 turns of No. 38 enameled wire, wound on a core the size of a $\frac{1}{4}$-w resistor. The shunting condenser used in the T-82 is a 500 $\mu\mu$f Ceramicon condenser. The impedance of the filament power supply is discussed in Section 3.4 on the fuze power supply, which covers both batteries and generators.

3.3.2 The Detonator

The detonator, as the connection between the fuze and the high explosive, is a critical part of the fuze. In order for manufacture of the fuze to be possible, the characteristics of the various fuze elements must be such that they can meet the requirements of the other components. The initial requirement is imposed by the high explosive [HE] used in the missile. In order to set off the HE the Army Ordnance Department required[212] the use of a tetryl (trinitrophenylmethylnitramine) booster. To assure a high-order detonation the Ordnance Department specified that the tetryl powder train should ample safety factor. The inner diameter of the HE, and a length of 0.75 in. will allow an ample safety factor. The inner diameter of the tetryl cup may be as little as 0.375 in. with no apparent diminution in the velocity of the shock wave. With the tetryl powder train specified by the Army, the problem arose of procuring an electric detonator which could initiate a high-order detonation in the tetryl, and which would not impose too severe requirements on the electric components.

Many squibs, detonators, blasting caps, and semicaps which were commercially available were tried, as well as an experimental high-impedance high-voltage detonator. For the initial fuze testing, the ND-5, a fast violent but poor flame-throwing squib made by the Hercules Powder Company, was used. This company then developed the ND-24 for use in these fuzes,

as an improvement over the ND-5. Although it functioned satisfactorily in the field tests, in which it was used to set off a potassium permanganate or a black powder spotting charge (cf. Chapter 8), it was not powerful enough to insure detonation of the tetryl booster. It therefore had to be abandoned. Hercules then developed a satisfactory detonator, which was known successively as the BS-4 or BS-5; the Detonator, Electric, T-3; the Detonator, Electric, M-2; and finally the Detonator, Electric, M-36. The latter three designations are official Army Ordnance nomenclature and indicate acceptance for use, first as an experimental item and then as a standard Army production item.

The M-2 electric detonator[212] (see Figure 40) itself consists of a three-element powder train. The bridge (heater) wire is embedded in about 0.2 g of mercury fulminate, which is followed by a primer charge of 0.13 $\pm$ 0.02 g of lead azide, which in turn detonates the base charge of 0.14 $\pm$ 0.02 g of pentaerythrite tetranitrate [PETN]. This construction permits a very compact assembly for the explosive powder train leading to the tetryl booster charge. The bridge wire, when heated electrically, supplies the energy to ignite the mercury fulminate and thus initiates the explosion. The heater wire is made of Nichrome and is initially 0.09 $\pm$ 0.01 in. long and is 0.00050 $\pm$ 0.00005 in. in diameter. In connecting the Nichrome wire to the copper lead wires, solder is dropped over the ends, so that only about half its length is effective in heating the mercury fulminate. The specified resistance for the detonator is 9 $\pm$ 3 ohms, allowing a 100 per cent variation between the minimum and maximum resistances and therefore between the minimum and maximum effective lengths.

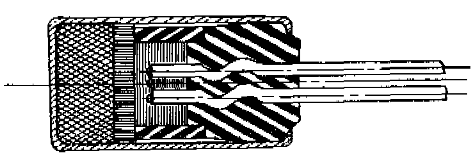

FIGURE 40. M-2 detonator used in radio proximity fuzes. This detonator was also designated BS-4 and M-36.

Time Lags. As the fuzes are used on projectiles traveling at high speeds, any time lag between the operation of the fuze and the explosion of the HE must be quite small. The delay inherent in the detonator may be broken down into three components: the time it takes for the incident electric energy to heat the Nichrome wire, the transfer of enough heat energy to ignite the mercury fulminate, and the explosion of the PETN base charge, which detonates the tetryl booster.

In operation, enough heat is generated in the bridge wire to melt it by the dissipation of over 1 millijoule of energy in it within 1 msec.[57] Nichrome melts at 1350 C, so that the grains of mercury fulminate adjacent to the bridge wire become immersed in a metallic bath at that temperature. The time between the liquefaction of the bridge wire and the explosion of the PETN is less than 0.2 msec. The Nichrome wire heats about 4 micrograms of mercury fulminate to its ignition temperature to start the explosion, which is thus initiated within a cylindrical layer about 0.00045 in. thick around the 0.00025-in. radius Nichrome wire.[57] The explosive wave travels through the tetryl booster after its initiation by the PETN, at over 7,000 m per sec, so that the time lag in the booster is less than 5 μsec. The time delay in the explosive elements is thus quite small. The overall time delay in the detonator is, however, influenced by the rate at which electric energy is dissipated in the Nichrome heater wire. If this rate is less than 70 mw,[57, 173] the heat produced will be conducted away through the detonator without igniting the mercury fulminate. In order to fire the detonator, energy must be supplied at a rate faster than it can be safely conducted away. The greater the energy dissipation is above this lower limit, the smaller the time delay. Further, in order to waste as little energy as possible in heat conduction, the total energy should be supplied in as short a time as possible. Thus, a constant energy dissipation of 1 w will fire the detonator in 1 msec. However, because of the thermal inertia of the mercury fulminate in contact with the Nichrome heater, energy dissipation at the rate of 25 w is required to decrease the total time to 170 μsec.

As a fuze may be used in the upper atmosphere, where the temperature is far below freezing, the possible effect of low tempera-

tures on the action of the detonator is important. The only measurable effect was that more energy was required for detonation at lower temperatures. This effect had been anticipated, but even at —78 C only about 10 per cent more energy was required.[166]

Leakage Resistance. Another characteristic of interest is the resistance between the detonator lead wires and its metal shell. This property is important because of the possible firing of the detonator by a voltage between the case and one lead or by leakage otherwise affecting the proper operation of the detonator circuit. The minimum resistance measured in a group of fifty detonators at ordinary temperature and humidity was 50,000 megohms. When subjected to a relative humidity of 95 per cent for 24 hours, the lowest resistance decreased to 12,000 megohms.[24] The effect of leakage resistances of these magnitudes upon the proper operation of the detonator circuit can be neglected.

Specifications. A summary of the pertinent operational characteristics of the detonator is given in the specification[212] which was used by the Army for large-scale procurement. An extract follows.

> The detonator shall function in an elapsed time not exceeding 0.005 second with an electrical current of not more than 0.175 ampere at 20°C, or with an electrical current of not more than 0.225 ampere at —15°C. Eighty per cent or more of the detonators shall also function in an elapsed time not exceeding 0.001 second, and none over 0.003 second with the discharge from a condenser of not more than 0.7 microfarad capacitance, charged from a battery of not more than 75 volts potential.

Some lots of detonators have had difficulty in passing the 0.175-amp specification, which is more severe than the other two; consequently, a recommendation that this current be raised to 0.200 amp was made.

3.3.3 The Detonator Capacitor

The capacitor is used in the detonator circuit as a very low impedance power source, which must store enough energy to fire the detonator. As far as the capacitor is concerned, the operation of the thyratron shorts a low resistance, on the order of 18 ohms, across it. With the minimum supply voltage specified as 125 v, the nominal capacitance required to insure that the detonator fires is 1 μf. A major requirement for the capacitor is that it must be small enough so that it does not occupy a disproportionate amount of the very limited space in the fuze. Although electrolytic condensers easily meet the space requirements, they were rejected at an early stage in the fuze development because of their many faults.[217] They deteriorate during storage and then require a long forming period, during which they pass excessive leakage current and store very little energy. They cannot withstand either low temperatures at high altitudes, or high temperatures of the tropics. In addition, all the energy stored in the electrostatic field is not immediately released, when the capacitor is shorted, because of dielectric hysteresis in the condenser. Paper condensers are therefore used as being the most efficient space utilizers which do not have these faults. In order to eliminate the deleterious effect of high-humidity conditions, the firing condenser is metal-clad.

In all the generator-powered fuzes, except those which use RC plate arming, the detonator firing condenser also serves as the part of the filter circuit of the power supply. The characteristics which determine its effectiveness in firing detonators are its capacitance, inductance, and internal series resistance. The dielectric absorption of a paper condenser is negligible for a single discharge. The leakage resistance is of only minor importance in a unit which does not use RC arming, as long as it is not so low that it presents an appreciable power drain on the generator. A 5-megohm leakage resistance will cause negligible drain on the power supply.

The series resistance and the inductance of the detonator firing capacitor are not measured separately; instead, a surge current test is made, which is intended to determine how well the capacitor will discharge through the detonator and thyratron. The capacitor is charged up to 135 v and then discharged through a 15-ohm resistor. The peak current is required to be 7 amp. As either inductance or series resistance in the condenser would lower the peak current, this test gives an indication of the

combined effect of both. Furthermore, as the condenser is actually used this way, the test is quite valid.

When measuring the peak surge current by discharging the condenser through the 15-ohm resistor, the impedance of the switch is in series with the resistor. The spark that occurs as the switch is closed represents a variable impedance which limits the peak surge current. It is, therefore, necessary to use a fast-acting mercury switch, rather than an ordinary switch.

The 7-amp limit was chosen because the better capacitors were able to pass this test, and the requirement allows a 100 per cent factor of safety in firing the detonator. In Figure 41 is shown the diminution in the peak surge current, due to the series inductance, when the 1.5 μf condenser used in the battery-powered fuzes is tested. As the time lag is also of interest, Figure 42 gives the time to peak current as a function of the inductance.

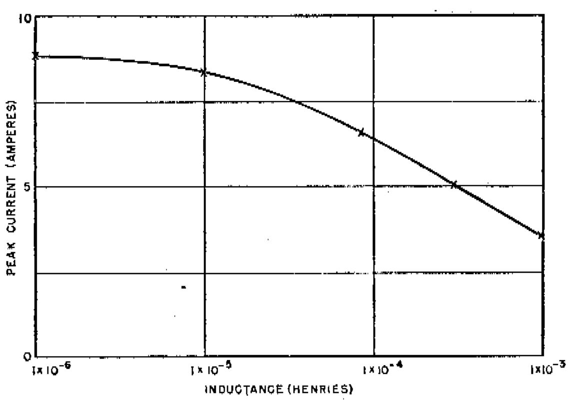

FIGURE 41. Effect of series inductance on peak surge current of detonator firing capacitor.

The possible effect of the inductance in decreasing the energy dissipated in the resistive component of the circuit was investigated. In the actual circuit, the thyratron stops conducting when its potential difference falls below about 20 v. The energy dissipated in the 15-ohm resistor was, therefore, determined as a function of the inductance for a 1.5 μf capacitor discharging from 135 to 20 v. Figure 43 shows that even a 100-μh inductance would decrease the energy dissipation less than 2 per cent. Thus, a capacitor would have to be quite poor for its associated inductance to have an appreciable effect. As shown in Figure 41, with so large a value of inductance the condenser would cause a peak current of less than 7 amp, and would, therefore, fail the peak surge current test. An

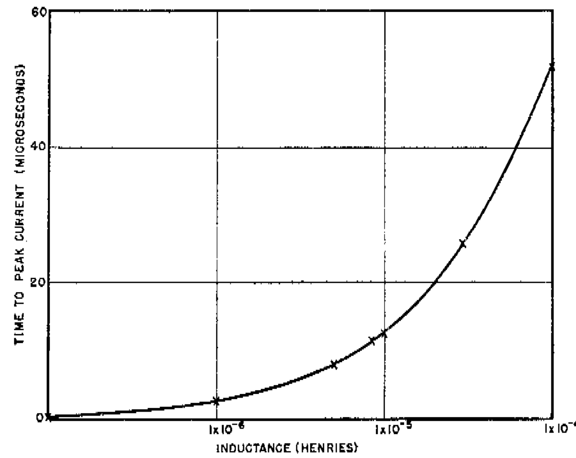

FIGURE 42. Effect of series inductance on time to peak surge current of the detonator firing capacitor.

inductance of 100 μh would decrease the peak surge current to 6.4 amp. The effect of the inductance on changing the time for the energy discharge is negligible. As shown in Figure 44, the time varies from 43 to 38 μsec as the inductance increases from 0 up to 100 μh.

The characteristics of capacitors may be affected by the ambient temperature and humidity, so that these factors must be taken into

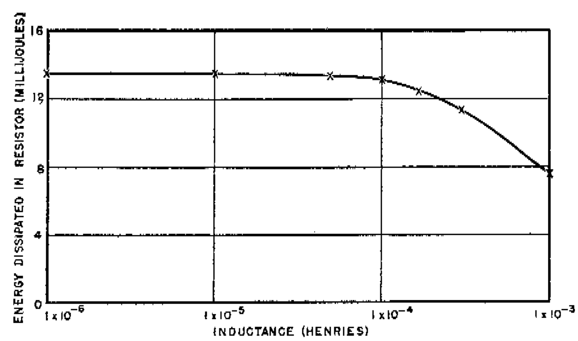

FIGURE 43. Effect of series inductance (associated with detonator firing capacitor) on energy dissipated in resistance load.

account.[166] The principal effect of a high relative humidity is to decrease the leakage resistance of the capacitor. It was found necessary to use metal-cased condensers in order to elimi-

[redacted]

nate this difficulty. Temperature variations affect both the capacitance and the leakage resistance of the condenser. At low temperatures the leakage resistance increases; at high temperatures it decreases, showing that the dielectric and the impregnating material have high negative temperature coefficients of resistivity, as might be expected. The capacitance decreases at low temperatures, so the condensers used must pass the specifications at the lowest operating temperature for the fuze. Moreover, it is well known that both the capacitance and leakage resistance change as a result of a temperature cycle.[217] Therefore, in order to determine how the condensers will react to different

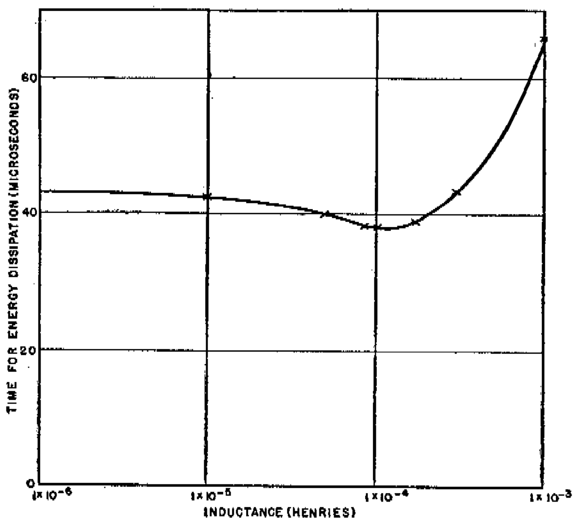

FIGURE 44. Effect of series inductance on time of capacitor discharge.

weather conditions, they must be temperature-cycled several times. Data are taken during each cycle, and the capacity and leakage resistance are required to meet the specifications throughout. Fairly large samples must be used in these tests in order that the data represent the condenser type, rather than just the samples tested. Another characteristic that is determined during these temperature and humidity tests relates to the mechanical strength of the condenser assembly, particularly to assure that the leads do not come out of the condenser. The temperature and humidity conditions do not affect the operations of the condenser in the peak surge current test. This is as expected, since the peak surge current is independent both of the capacity and of the leakage resistance if it is greater than 1,000 ohms.

3.3.4 The Thyratron

The thyratron is used in the variable-time [VT] fuze as an extremely sensitive electronic switch. Rather stringent requirements are placed on the thyratron by the physical size of the fuze, the available power supply, the characteristics of the oscillator and amplifier sections, the detonator, and discharge condenser, and the use to which the fuze is put.

Because of the limited volume of the fuze, it was necessary to develop a thyratron[8] occupying not more than ¼ cu in. of space. Into this space were fitted the components required to give the thyratron the electric characteristics required by the factors noted above. These requirements were established as follows:

Low Power Consumption. In both battery and generator powered fuzes the available power is distinctly limited. (See Section 3.4.) It was, therefore, necessary to design the filament for the lowest possible power consumption consistent with the required life and surge characteristics of the tube.

Critical Grid Voltage. An allowable range of -2.1 ± 0.4 v for critical grid voltages was dictated by the amount of bias voltage which could be incorporated in the battery and the available signal level from the oscillator-amplifier section of the fuze.

Effective Critical Grid Voltage. The value for critical grid voltage defined above is for d-c operation. When the thyratron filament is powered by alternating current the critical grid voltage is increased because the filament potential is negative during half of each cycle, and the critical grid voltage is referred to the most negative portion of the filament. As installed in a fuze circuit the thyratron grid receives transient and ripple signals from the amplifier. The phase of the ripple signal is usually such as to reduce the effect of a-c ripple on the thyratron filament. The highest negative bias at which the thyratron will fire, under operating conditions, is called the effective critical grid voltage.

Stability. Supply voltages of generator-powered fuzes are generally higher than those powered by batteries. In addition, the battery voltages change considerably with age and climatic conditions. These factors necessitated a thyratron whose critical grid voltage was as insensitive as possible to changes in operating voltage both from the standpoint of magnitude and the ability of the grid to maintain control.

Surge Characteristics. The properties of the detonator and discharge condenser, together with the nature of the fuze application, determined the required surge characteristics. The thyratron must be able to pass peak surge currents of the order of 7 amp in 0.001 sec after triggering, in order to transmit the energy from the discharge condenser to the detonator in a time short enough to set up a high-order detonation at the same point in space at which the triggering signal was received, the speed of missile being approximately 1,000 to 1,500 fps.

Leakage and Grid Current. Both leakage between plate and grid and grid current contribute to unstable critical grid voltages and therefore must be minimized. Where RC arming is used in addition to mechanical arming, leakage between plate and filament is important and must also be minimized.

Microphonics. Because of the multitudinous vibrations and shocks to which the tube is subjected in operation it was necessary to have the thyratron mechanically strong, so that it would not operate prematurely.

Life. Although the fuze itself needs to operate only once, a certain amount of testing is required prior to use. Since it appeared that one way to obtain all the required electric characteristics in so small a tube was to sacrifice greatly in the time of useful operation, it was necessary to preserve sufficient reserve to guarantee proper operation after the testing. Further limitations are discussed in Section 3.1.4.

The first step in obtaining a suitable thyratron was to examine the existing types of small tubes. Tests were made on the Bell Telephone Laboratories type 1278 GY-2 (see Figure 45), the General Electric miniature thyratron and the Sylvania type SN-738.[6] The 1278 GY-2 was soon eliminated as a possibility for several reasons. Although the critical grid voltage of this type was too high and spread over too great a range, the principal objection was the manner of construction of the tube itself. The geometry of the tube was such as to make it susceptible to external fields, making it impossible to use the tube in closely packed assemblies without careful external shielding. This was undesirable because of the premium on space.

The GE miniature thyratron[8] had the disadvantages of excessive size, susceptibility to external leakage caused by handling, and a limitation of the number of times it could be surged. Because of its manner of construction, it had a distinct advantage in that the critical grid voltage could be very closely controlled, both as to magnitude and stability. It was, therefore, decided that the size should be reduced and an attempt made to reduce the susceptibility to leakage and improve the surge characteristics.

The Sylvania SN-738 had been developed for Section T and, in general, was found to have the proper characteristics with the exception that it was designed to operate at low voltage and exhibited poor performance at the higher voltages used in Division 4 fuzes. It was decided that this tube should be redesigned to operate at the higher voltages and also to eliminate certain classified features peculiar to the original purpose for which it was designed.

The redesigned GE and Sylvania thyratrons were known as the microthyratron and SA-782 respectively (see Figure 45). The microthyratron preserved all the advantages of close grid control found in the miniature thyratron and largely eliminated the problem of leakage by virtue of a special lacquer coating over the surface of the tube. The microthyratron is essentially a cold cathode tube, having a filament supplying only enough emission to initiate the discharge which immediately transfers to an anodized aluminum spotting tab. This tube was finally abandoned, because it was not possible to maintain the filament emission at the proper value over the range of filament voltages to which the tube was subjected, nor was it possible to obtain a spotting tab which would stand the punishment of repeated surging of the thyratron.

The Sylvania thyratron in its final form as

[redacted]

the SA-782B (shown in breakdown in Figure 46), meets all of the requirements outlined above. The outstanding features in the design of this tube were the introduction of an additional grid between the control grid and the anode and an auxiliary shield around the filament above the top mica. The additional grid is connected to the negative leg of the filament and makes possible a lower critical grid voltage than is otherwise consistent with the geometry of the tube and also controls the spread of critical grid voltage from tube to tube. The auxiliary shield is connected to the control grid and makes stable operation possible at higher than normal voltages. This shield was necessitated by the fact that the emitting portion of the filament sometimes extends above the top mica and at sufficiently high anode voltages causes an arc-over to the anode because of the absence of grid control in that part of the tube.[8, 67, 189, 202, 213]

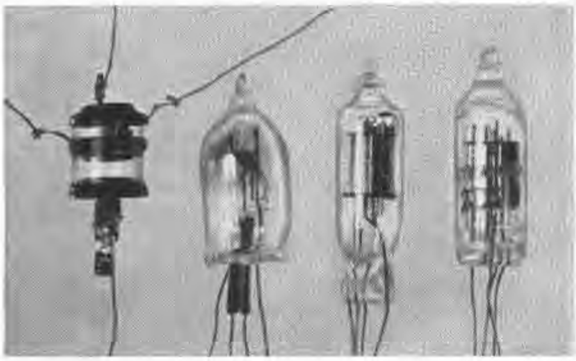

FIGURE 45. Various thyratrons developed and considered for use in radio proximity fuzes. From left to right they are: GE microthyratron, BTL 1278 GY-2, GE version of Sylvania thyratron, and Sylvania SA-782B. The latter tube was also known by the NDRC designation NS-4 and the Signal Corps designation 2D29.

3.3.5 Circuit Operation

The sequence of operations in the fuze after the projectile is released is such that it can function as soon as arming is completed. Upon release the generator propeller starts to turn, and it reaches the equilibrium rotational velocity, due to its speed through the air, in 5 to 6 revolutions. The tube filaments warm up within 0.4 sec,[11] and both oscillator and amplifier are in operation. The B voltage has already reached its steady-state value. However, the fuze cannot function, because the electric detonator is not yet connected to the firing circuit. The details of mechanical arming are covered in Chapter 4; here it will suffice to state that a preset number of turns of the fuze propeller is required before the detonator makes electric contact. Until this time, the detonator is separated from the tetryl booster by a ¼-in. thick brass plate. Upon arming, the detonator bridge wire is connected between the detonator firing condenser and the thyratron plate. Except when using RC arming (see Section 3.3.6), the firing condenser is also the output filter condenser and is already charged up to the operating potential of about 140 v. At electric arming, therefore, a 140-v positive pulse is applied to the thyratron plate. A part of this arming pulse appears on the thyratron grid in the ratio of the grid-to-filament impedance to plate-to-grid impedance. In order to prevent this grid pulse from firing the thyratron, the grid-to-filament impedance is reduced by connecting a condenser from grid to ground (shown in Figure 39). In the early fuzes a 50-μμf condenser was used and was quite satisfactory. In later production fuzes, when a 500-μμf condenser was used in order to get proper amplifier shaping,

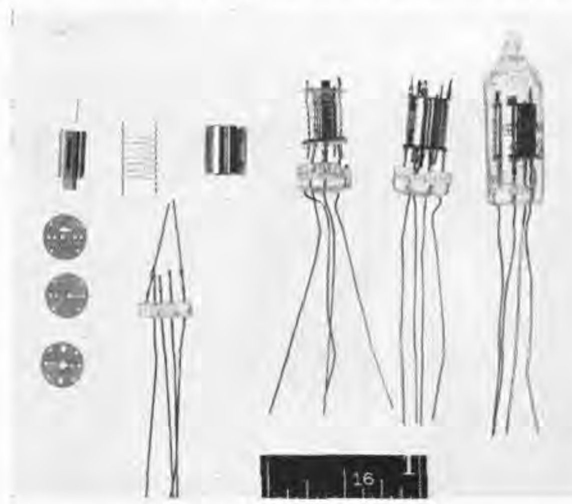

FIGURE 46. Breakdown of thyratron showing electrode SA-782B structure.

an additional safety factor was provided. The presence of this arming pulse places an additional requirement on the thyratron; the leakage resistance from the plate to the grid must be quite large, on the order of 1,000 megohms. At any time after arming, a sufficiently large signal, 3 to 4 v positive, impressed on the thyratron grid by the amplifier, will fire the thyratron; and the condenser will discharge through the tube and the detonator, initiating the explosion.

Just as there is a time lag for a signal to travel through the amplifier,[54] so there is a time lag between the incidence of the firing signal at the thyratron grid and the explosion of the detonator.[25] This time lag is on the order of 1 msec and is almost entirely due to the detonator. The delay due to the thyratron is usually less than 150 μsec[189] and that due to the condenser is less than 60 μsec. One millijoule of energy dissipated in the detonator in 1 msec will set it off; in order to decrease this time lag, it is necessary to dissipate more energy, faster, in the detonator. For example, this time delay can be reduced to 200 μsec by dissipating 3.6 millijoules in it in this time.[58]

Component Values. To determine the efficiency of a given capacitance in firing a detonator, a condenser of the given size is used to fire detonators through thyratrons in the detonator circuit. The condenser potential is initially too low to fire the detonator when the thyratron fires, and it is gradually increased until the detonator does function.[25] By using several thyratrons, detonators, and condensers, the spread in firing voltage due to variations in these components is determined. These data are important to determine the minimum capacitance that may be used to fire the detonator.

Tests were made on the detonator circuit, with all components, beyond the extreme temperature limits foreseen for actual operation, namely, −78 C and 60 C, to determine the effects of extreme temperatures. The power supply specifications permit a minimum B voltage of 125 v under normal conditions; however, at low temperature the efficiency of the selenium-button rectifier assembly decreases. At −40 C, the normal output of 135 v will be only 106 v 1 sec after launching,[69] at which time a rocket fuze should be ready to function. This B voltage was used in some of the tests, as was the minimum expected A voltage, 1.17 v rms.[178] The filament series resistor lowered the thyratron filament voltage still further. It should be noted that this lowered filament voltage actually has a beneficial effect. Although the decreased filament emission increases the thyratron time delay, this time is still sufficiently small. In addition, because of the lower filament operating temperature, the filament resistance is lower. This decreased series resistance permits a larger fraction of the condenser energy to be dissipated in the detonator. After making allowances for all the other factors which influence the operation of the detonator circuit, it was found that the minimum capacitance which would fire any good detonator, using any thyratron which passed the tube tests, was 0.96 μf.[58] It became apparent in these tests that the largest single variable in determining the firing capacitance and voltage needed was the thyratron, although all the tubes used had passed the tube tests.

The thyratron is used as a low-impedance switch to permit the energy stored in the condenser to be dissipated in the detonator. About 40 per cent of the condenser energy is actually transferred to the detonator.[6]

The minimum capacitance value can be further lowered by a selection test for thyratrons[58] (this technique was not used in production). Such a test measures the efficiency of the thyratron in permitting energy transfer. Rejection of less than 5 per cent of the thyratrons which pass the thyratron specification tests would lower the minimum value of the thyratron-firing capacitor to 0.87 μf. With further division of the tubes into two approximately equal groups, the better group would permit the use of an 0.5 μf firing capacitor in fuzes where the space requirements are critical. The other group of thyratrons could be used in the larger fuzes, where the space requirements are not so stringent.[58]

3.3.6 Electric (RC) Arming

The use of a resistance-capacitor network to delay arming provides a delay in electric arm-

[redacted]

ing (RC) after mechanical arming has occurred.[58] It consists of placing a large resistor, on the order of a megohm, between the single filter capacitor used with RC arming and the detonator firing capacitor. At mechanical arming the detonator firing capacitor starts charging. The fuze cannot function until the capacitor potential is high enough to set off the detonator if the thyratron should fire. The detonator firing capacitor and the arming resistor are shorted by a large resistor, so that there is no charge on the capacitor before mechanical arming occurs.[181] A diagram of the circuit as used in the T-171 is shown in Figure 47. The time delay before electric arming is proportional to the size of the arming resistor. Time delays up to approximately 8 sec can be

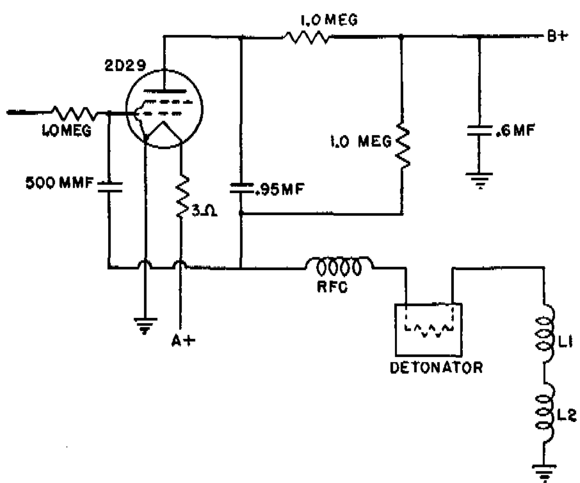

FIGURE 47. RC arming circuit of T-171.

achieved by proper choice of the resistance. An upper limit is set by the leakage resistance of the capacitor,[163] in comparison with the series resistor used. Also of importance is the accompanying elimination of the arming pulse when RC arming is used.

The data on the potential necessary on a particular capacitance to fire the detonator are of primary importance when RC arming is used, since they permit the calculation of the time interval between mechanical arming and electric arming.[56] This period is the time taken for the capacitance to charge to the firing voltage, and it is a function of the supply voltage, the capacitance, the arming resistance, and of the particular thyratron and detonator. In making arming calculations, the median voltage required to fire a detonator through a thyratron using a particular capacitance is used, rather than the average voltage. The median voltage is the voltage which will fire half the detonators, and it represents the firing data much better than does the average voltage, which is unduly influenced by extreme values due to atypical components. The data on firing detonators using different capacitances are summarized in the following table.

Median voltage required to fire detonator.

Capacitance	Median voltage
0.3	96.5
0.37	93.5
0.5	84.0
0.75	74.0
1.0	69.2
1.335	63.0
1.555	60.0
1.7	59.0

The above values are plotted in Figure 48 as the simplest method of averaging all the data, as well as permitting determination of the median voltages required for capacitances not used in the tests.

Another method for averaging the data is to fit a least squares curve to the points on the graph, with the added advantage of permitting algebraic computations with the resultant equation. As the data are the voltages required for various capacitances to fire the median detonator, just enough energy is dissipated in the detonator to fire it. The least squares curve, therefore, indicates a constant energy dissipation in the resistive portion of the detonator circuit. It also shows the condenser potential at detonation to be very nearly equal to the constant voltage drop V_f of both the gas in the thyratron when it is conducting and the contact potentials in the tube.

The condenser, initially charged to a potential V, stores an amount of energy

$$W_i = \tfrac{1}{2}CV^2. \tag{33}$$

After detonation, the residual energy on the condenser is

$$W_f = \tfrac{1}{2}CV_f^2. \tag{34}$$

After the thyratron starts conducting, before the arc starts, the condenser potential drops to

V_a, and the energy loss, almost all of which is dissipated across the gas in the tube, is

$$W_a = \tfrac{1}{2}CV^2 - \tfrac{1}{2}CV_a^2. \qquad (35)$$

From the initiation of the arc to its extinction, the constant potential V_f, due to both the tube contact potentials and the gas, causes an energy loss of

$$W_t = QV_f = (CV_a - CV_f)\,V_f. \qquad (36)$$

The energy dissipated in the resistive portion of the circuit is

$$W = W_i - W_f - W_a - W_t,$$

$$W = \tfrac{1}{2}CV^2 - \tfrac{1}{2}CV_f^2 - \tfrac{1}{2}C(V^2 - V_a^2) - CV_f(V_a - V_f). \qquad (37)$$

Solving,

$$W = \tfrac{1}{2}C(V_a - V_f)^2. \qquad (38)$$

As the experimental datum is V,

$$W = \tfrac{1}{2}C(V - V + V_a - V_f)^2,$$

or

$$W = \tfrac{1}{2}C[V - (V - V_a + V_f)]^2. \qquad (39)$$

The least squares fit of this equation gives values of $W = 0.67$ millijoule, and $V - V_a + V_f = 31.6$ v. V_f is about 18 v, so that $V - V_a = 13.6$ v, which is approximately the condenser potential drop before the thyratron arc strikes. This value has been verified by oscilloscope measurements.[58] As both these voltage drops are due to the thyratron, the equation may be rewritten, $W = \tfrac{1}{2}C(V - V_t)^2$. The current during the initial 13.6-v drop is comparatively small, and most of this energy is dissipated in the tube in starting the arc with only a negligible amount of it dissipated in the detonator. It should be noted that any energy stored in the magnetic field of the circuit inductance at peak current has been dissipated in the resistive portion of the circuit by the time conduction stops.

Several points from equation (39) are plotted as the circles in Figure 48 using the above value for the bracket term, but the complete graph was not drawn because it is almost indistinguishable from the curve drawn through the experimental points. The excellent fit to the eight experimental points, using a two-parameter equation, validates the form of the equation as being the type to which the data conform. As this equation is approximately a straight line on log-log graph paper, the experimental points were plotted on such paper as in Figure 49. The curve which fits them best is the straight line drawn through them. The points from the theoretical curve are also plotted in Figure 49.

Using the experimental data for the median voltages to fire detonators through thyratrons with various capacitances and assuming an average unit B supply of 140 v, the equation

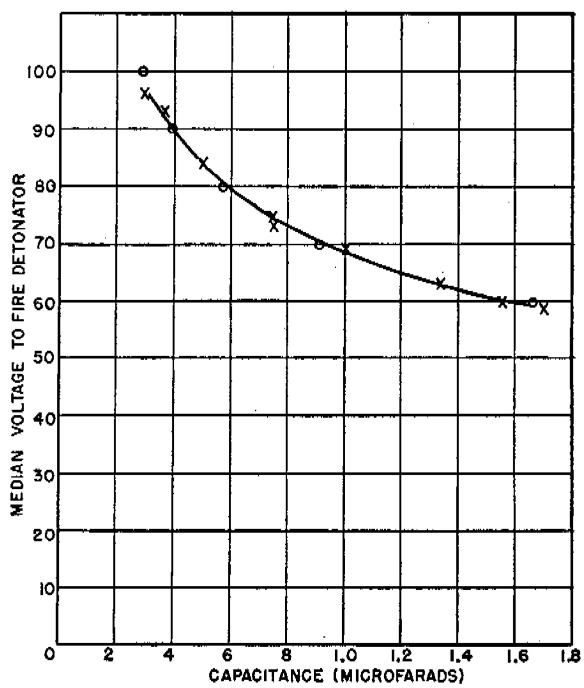

FIGURE 48. Median values of voltage on capacitors necessary to fire detonators through thyratrons for various values of capacitance.

$t/R = -C \ln (1 - V/V_0)$ was solved for a value of t/R to correspond to each pair of capacitance and firing voltage values.[58] The t in this equation is the time delay in charging a capacitance C to a voltage V through a resistance R, using a supply voltage V_0. These points, which represent data for 250 thyratrons, are plotted in Figure 50, where the time in seconds divided by the resistance in megohms is plotted against the capacitance in microfarads. This curve can be used to determine the median electric arming time in fuzes using RC arming for any resistance value, and the curve extends be-

yond the values of capacitance that have been used in the fuzes to date.

The spread in arming times around the median values due to variations in the components has been represented in Figure 51, which can be used to find the actual time in which a given percentage of the fuzes with a certain median arming time will be electrically armed.[56] In making the calculations, it was assumed that both the resistors and the condensers were within 10 per cent of their nominal values, with every value in this range equally probable. The supply voltage was assumed to vary between 125 and 160 v in a parabolic probability distribution, with the center value three times as likely as the extreme values. The distribution of detonator firing voltages, using a given capacitance, was experimentally determined, using many thyratrons

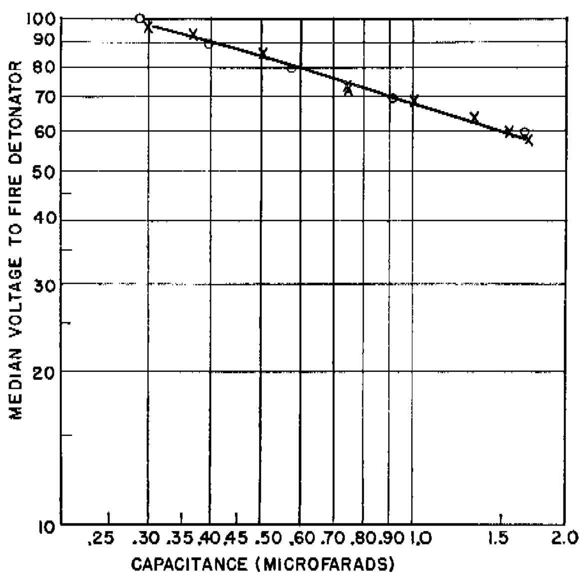

FIGURE 49. Median values of voltage on capacitors necessary to fire detonators through thyratrons for various values of capacitance on log-log scale.

and detonators. It was also assumed that the leakage resistance of the condenser was high enough so that it would not affect the condenser potential appreciably. This assumption requires that the leakage resistance be greater than 40 megohms when a 2-megohm arming resistor is used, and greater than 25 megohms when a 1-megohm arming resistor is used.[163] As previously noted, the thyratron is responsible for most of the spread in arming time.

Dumping. The use of RC arming is of decided advantage when the tactical use of the

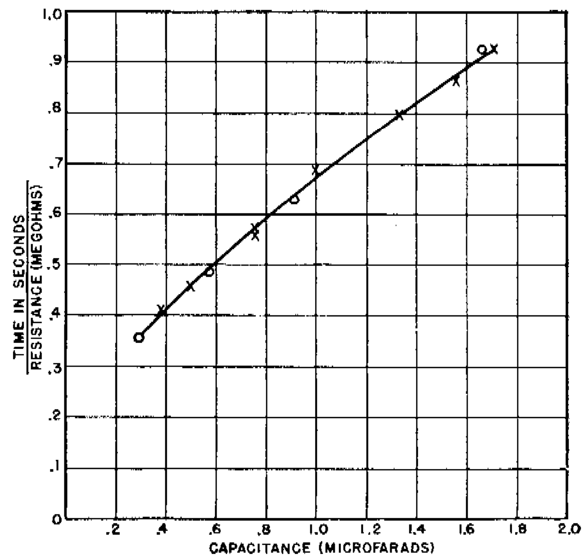

FIGURE 50. Median arming time in RC circuits as related to resistance and capacitance values.

fuze is such that spurious signals of firing magnitude are possible shortly after mechanical arming.[84] For example, as used on rockets, the phenomenon known as afterburning, whereby, after the main burning of the propellant is over, additional slivers of propellant ignite; the rocket expels quantities of luminous gas and produces several random, intermittent signals of several times firing magnitude. With RC arming,[58] if a firing signal is impressed on the thyratron grid before the plate potential has reached about 38 v, a low-current discharge will start through the thyratron, gradually discharging the detonator firing condenser. When the signal is over, the thyratron grid regains control of the tube, the discharge stops, and the condenser starts to charge up again. If the firing signal occurs after the thyratron plate potential has exceeded 38 v but before the condenser has stored enough energy to fire the particular detonator through the particular thyratron, an arc discharge takes place. The condenser potential drops to about 18 v, after which the grid regains control and the condenser starts to charge up again. This occur-

rence is known as "dumping." In the arc discharge, the thyratron begins to conduct within 10 μsec after the signal is impressed on the grid. The effective thyratron impedance decreases to about 10 ohms, thus permitting a very high peak surge current in the neighborhood of 6 amp. The discharge is over within about 50 μsec. When used with rockets which suffer badly from afterburning, this phenomenon of dumping permits the use of radio proximity fuzes without undue incidence of early functions. At the same time, it permits the fuze

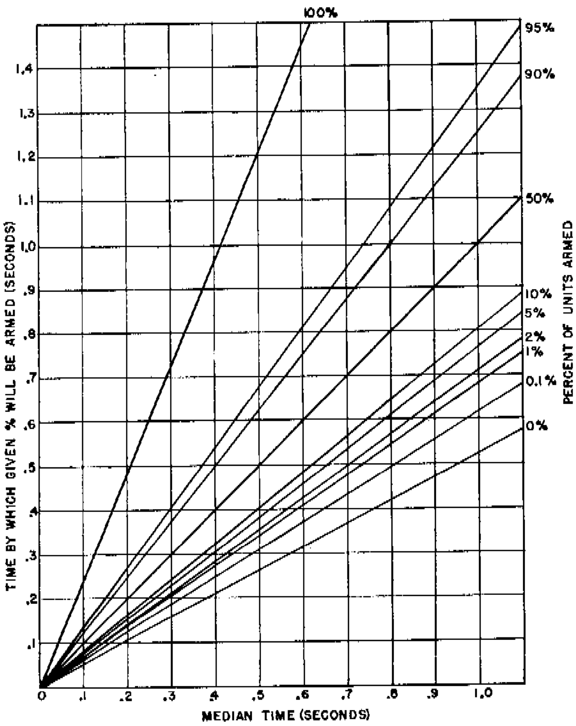

FIGURE 51. Distribution of RC arming times in terms of the median arming time.

to function properly within the shortest permissible time after burning has stopped. If afterburning is severe, the thyratron may dump several times before electric arming occurs. In this way, the use of RC arming provides insurance against premature fuze functions which might otherwise occur shortly after mechanical arming.

Arming Pulse Protection. In some of the fuzes, such as those designed for use on mortar shells, mechanical arming causes a pulse to originate in the oscillator. This voltage pulse cannot be protected against by means of the condenser in the thyratron grid circuit, which only decreases the effect of the thyratron plate pulse. The use of RC arming does eliminate the effect of such arming pulses, but it requires the use of a detonator firing condenser in addition to the filter condenser. This necessitates the allocation of space to two large components in the fuzes where the space requirements are most critical. As there are no afterburning problems with a mortar shell, an electric arming system which would eliminate the effect of the arming pulse is all that is necessary. Such a system has been developed which also permits the use of the same condenser for filtering the rectifier output and for firing the condenser. The scheme consists in having large negative voltage on both the thyratron and amplifier grids, in addition to the normal grid bias, before mechanical arming. This C voltage is large enough to bias the amplifier tube beyond cutoff. At mechanical arming the additional C bias is eliminated, permitting the amplifier to start functioning. The time constants in the fuze circuits are so adjusted that the arming pulse from the oscillator is harmlessly over before the amplifier has reached its normal operating point and before the thyratron grid bias has reached its normal value.

Other Arming Methods. Several other electric arming methods have been used during the development period. One method of eliminating the pulse which occurs at arming is to use a system which does not change the potential at any point in the fuze. Two of the systems involve only the detonator, which must fire in order to initiate the explosive in the projectile. The first one consisted of having a wire shorting the detonator before arming, so that all the circuits would have reached equilibrium by the time the detonator was unshorted at arming. This method was abandoned because it did not assure perfect safety, because of the possibility of the shorting contact opening prematurely due to vibration or shock. Moreover, there was difficulty in keeping the thyratron in the nonconducting state at arming if a firing signal reached the thyratron grid before arming. This method was thus used primarily as a safety device rather than as an arming method. It was replaced by a system which used a 10-

megohm resistor in series with the detonator. The resistor was shorted at arming. If the thyratron fired before arming, the 10-megohm resistor limited the current flowing through the detonator to a very small value, on the order of 12 μa, so that the heat generated in the detonator could be safely dissipated. This current is so small that, even if all the heat energy produced on the detonator bridge wire remained there, it would take several hours to initiate the explosion. The factor of safety involved is enormous. The minimum constant current which will fire the detonator is about 90 ma,[173] and the detonator will function in about 5 msec. The heat produced by any small current can be safely conducted away[57] through the mercury fulminate, which initiates the explosion in the detonator. This arrangement is much safer because it is possible to place the contacts so that accidental operation due to vibration or shock is impossible. It also permitted the inclusion of a self-quenching feature, if the thyratron fired before arming, by connecting a condenser between the thyratron plate and ground. This system was the precursor of RC arming.

Other arming systems tried also permit the thyratron plate to be at its operating potential and rely on preventing the thyratron from functioning and thus preventing detonation. In one of these systems a large negative bias is impressed on the thyratron grid, which is removed at arming. In order to improve this method, an RC time delay was added at the thyratron grid to prevent functioning immediately after arming had occurred.

Another arming system was used in some of the experimental fuzes developed at the Bell Telephone Laboratories.[204] The pentode screen resistor is connected to B+ through the thyratron plate network. Until mechanical arming, when the thyratron plate circuit is closed, the pentode screen potential is slightly negative, because it assumes an equilibrium potential due to the electron current in the tube. The gain of the amplifier with this screen potential is virtually zero and consequently no signals are passed to the thyratron. After mechanical arming there is a time delay during which the screen by-pass condenser is charged, before the amplifier gain reaches its normal value. The voltage transients due to the arming process are over before the amplifier is operative, so that none of the arming transients can cause the fuze to function prematurely. Furthermore, as the pentode becomes operative, its plate potential drops from B+ to its normal operating potential and transmits a large negative pulse of short duration to the thyratron grid. Still another method, the principle of which is still in use, is to operate the thyratron filament at a lower voltage than the other tube filaments, thus increasing the time delay before the thyratron can function beyond that of the rest of the fuze. In this way, most pulses are over before the thyratron becomes operable. The lower thyratron filament voltage is obtained by increasing the resistor in series with the thyratron filament. As used on generator-powered fuzes, the net effect is that a higher rotational speed is required for the thyratron to be able to function than for the other tubes.

3.3.7 Safety Features

This part of the report deals only with the electric safety features, many of which have already been discussed in the preceding parts of this section dealing with electric arming. Actually, the two are very closely related. The primary method for assuring that the fuzes will be entirely safe in the unarmed position is to make certain that no current can flow through the detonator heater wire. This may be done either by having the detonator open-circuited before arming, which is the method used in all production fuzes, or by having the detonator short-circuited before arming. By relaxing the no-current requirement to permit a minute current, the use of the 10-megohm resistor in series with the detonator might also be included in this classification.

The other possible electric safety feature is to prevent the thyratron from firing prematurely and thus prevent detonation. The methods used are RC arming in either the plate circuit or the grid circuit of the thyratron. An additional safety feature common to all generator-powered fuzes is that, as long as the generator is not

turning, there is no electric energy available in the fuze. Hence, the detonator cannot fire. Of course, this last feature depends on the existence of a leakage path across the detonator firing condenser, so that the condenser will not still be charged from the previous occasion when the generator was functioning.

3.3.8 Self-Destruction

Electric self-destruction [SD] was used in many of the battery-powered fuzes (T-5). When these fuzes are used as antiaircraft weapons over friendly territory, it is necessary to prevent them from exploding on ground approach

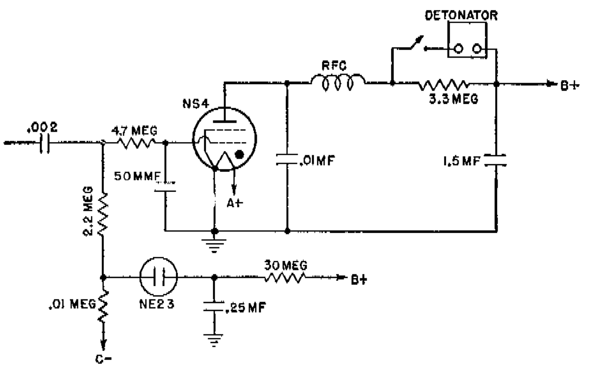

Figure 52. Self-destruction circuit used in T-5 fuzes.

and inflicting casualties. The method used was to explode the fuze from 6 to 11 sec after the missile was launched, if it had not already functioned. This time limit was long enough so that, if the projectile were going to function on a target in combat, it would already have done so. The SD device consisted of an RC time-delay circuit (shown in Figure 52) at the thyratron grid, which was connected to a neon tube. The neon tube used was the General Electric Company [GE] NE-23, a 1/25-w lamp in a T-2 bottle. When the condenser potential reached the striking potential of the neon tube, the condenser discharged through the neon tube, and thus fired the thyratron, which in turn set off the detonator. The time delay in this circuit is a function of the resistance, the capacitance, and the battery voltage, as well as of the neon tube striking potential. In fact, this last factor caused the largest variation in the time delay. If the neon gas is relatively unionized the striking potential may be increased as much as 30 per cent above its normal value. Methods used for keeping the gas sufficiently ionized to minimize variations in striking voltage were to channel light to the neon tube through a Lucite window, and thus ionize the gas photoelectrically, and to place a little radioactive material on the tube envelope. It was found that cosmic radiation did not keep the gas sufficiently ionized.

3.4 POWER SUPPLIES[g]

3.4.1 Requirements

The radio-type proximity fuze requires an electric power supply which provides filament, plate, and grid bias voltages to the electronic system and which ultimately delivers a current surge to the electric detonator upon actuation of the fuze. The power supply has, therefore, a position of prime functional importance. The quality of overall fuze performance cannot exceed that of the power supply. Much effort has been directed toward the design of a power supply meeting the varied requirements peculiar to proximity fuze operation.

Because of the urgency of the program it was not practical to follow an optimum procedure of setting up rigid functional specifications for each part of the device and aiming all development to these prescribed requirements. Instead all parts of the device were under simultaneous development toward rather elastic specifications. Progress of one phase invariably produced a concomitant change in the minimum requirements of another phase.

The initial goal was to realize rapidly a fuze design which would provide consistent function even if expediency required compromise of the ultimate qualities which were visualized for the fuzes. Subsequent redesign was relied on to introduce improved versatility, performance

[g] This section was written by J. G. Reid, Jr., of the Ordnance Development Division of the National Bureau of Standards.

[redacted]

quality, ruggedness, and simplicity of construction. This general philosophy held not only in the design of the unit as a whole but also in the design of subassemblies, such as the power supply. The following general specifications for the power supply developed during progress of the work. They represent partly initial ideas and partly modifications imposed by service considerations.

The primary requirement upon the power supply system is to furnish adequate operating power to the electronic system. No compromise can be made on this point. Accordingly, minimum requirements for A, B, and C supply were established on the following bases:

Filament Supply. Circuit designs utilized electron tubes of maximum 1.5-v nominal filament operation. Other tube types requiring lower filament voltages were adapted to 1.5-v supply by use of the proper filament dropping resistors. At normal filament voltage various tube types drew currents ranging from 70 to 220 ma. The tube complements of various fuzes had filament requirements ranging from 450 to 750 ma, equivalent to 0.6 to 1.1 w. The foregoing are d-c values or rms a-c values.

Plate Supply. Plate current demands of the electronic systems of various fuzes were relatively uniform. Radio-frequency oscillators drew an average of 12 ma at 135 v with a spread of about ± 2 ma. Amplifiers in all cases drew less than 0.5 ma at 135 v. Thus, total plate circuit requirements lay between 2 and 3 w supplied at 135 to 150 v.

Bias Supply. Negative grid-bias voltages of about 6 v to the thyratron and 1.5 v to the amplifier were also required of the power supply. These voltages were applied to such high-resistance loads that the power involved was negligible.

Detonator Firing. Type BS-4 and BS-5 detonators (see Section 3.3) were used in all fuzes developed by Division 4. Actuation of either of these required an internal dissipation of 1 millijoule of electric energy within the duration of 1 msec, or great energy over a longer period. A minimum of approximately 5 millijoules was required from the power supply within 1 or 2 msec, the excess supplying energy losses elsewhere in the firing circuit and insuring consistent function of the detonator. As explained in Section 3.3, it was found expedient to draw this energy from a noninductive capacitor, 1 mf or more in capacitance and charged to the voltage of the plate supply, i.e., at least 100 v. This corresponded to a current peak in excess of 6 amp. The charging of the detonator-firing capacitor represented a negligible load on the power supply. However in power sources where the terminal voltage deteriorated with time the lower voltage limit required for the capacitor became very important.

Life. It was required that the power supply maintain adequate voltage and power over an operating period of at least 1 min. Testing requirements presented additional demands and when the fuze power supply was used for test purposes (in production) approximately 10 min additional life was essential.

Indefinite shelf life of the power supply was desired but this requirement was waived in some of the earlier battery-powered fuzes.

The power supply was required to operate compatibly with the electronic system of the fuze, not only in supplying operating voltages sufficiently constant and noise free, but also in not introducing excessive electric or mechanical disturbance by its own operation.

Stability. Relatively small fluctuation in the B supply voltage could cause fuze malfunction. If the noise frequency coincided approximately with that of amplifier peak gain, 0.03 per cent magnitude was sufficient amplitude. Random fluctuations of nearly twice this value were permissible. Fluctuation in the A supply of about the same absolute amplitude (or 100 times greater in percentage) was tolerable. In summary, the voltages supplied had to be essentially noise free. The precise value of tolerable noise depended on the character of the noise. This has been discussed in Sections 3.1 and 3.2.

It was further necessary that the power supply, if it contained any moving parts, introduce a minimum of mechanical disturbance to the electronic system. The maximum tolerable amplitude of vibration cannot be specified. It depends necessarily on the type of construction and the care that has been taken in designing both circuits and components. It can be noted

[redacted]

that the use of high-speed rotating or vibrating parts was recognized as a possible source of mechanical disturbance and consequent awkward design problems.

Ambient Conditions. The range of ambient conditions for fuze operation was made progressively broader. For the majority of the fuzes developed, satisfactory operation was required in the temperature range from −40 to +60 C, and from 0 to 100 per cent relative humidity. This overall requirement was imposed also on the power supply. Further it was desirable that proper fuze operation be obtained after the unpackaged fuze had been maintained under any such conditions for as long as 24 hours prior to use.

The fuze, including power supply, was, with suitable moistureproof packaging, to have an indefinite shelf life under the same ambient conditions as for operation.

Ruggedness. Minimum requirements for the mechanical strength and ruggedness of the power supply were identical with those for the fuze unit as a whole. In use it should perform satisfactorily after setback (for rocket application, $250g$ maximum; for mortar application, $10{,}000g$ maximum). No unusual precautions should be required in fuzing or in the handling of fuzed projectiles beyond the care exercised in handling ordinary point-detonating fuzes. The packaged bulk lots of fuzes should be capable of withstanding the rough handling such items customarily encountered in field storage and delivery.

Size. With regard to physical design it was desirable that the power supply be small and of proper shape to match the remaining sub-assemblies of the fuze. The particular volume corresponding to "small" was progressively reduced as the program advanced. In first designs the power supply was allotted about 12 cu in. in the shape of a cylinder 2.5 in. outside diameter and 2.4 in. long. In later models the total volume was reduced to less than half this value.

It was a prime requisite that the power supply be adaptable to quantity production, at least with regard to simplicity of construction. Economy of material was not a basic consideration except in the case of strategic war materials.

3.4.2 Survey of Possible Sources of Power

In the development of a power supply to meet the foregoing specifications, serious consideration was reduced to two general types, those using batteries to derive the required electric energy from a chemical source and those employing electric generators driven by an input of mechanical energy.

The electric demand upon the supply was a maximum of 3 w for the plate circuit and 1 w for the filaments. With a design excess of 25 per cent this indicated 5 w for the power supply output. The service life was to be a maximum of 60 sec. Thus, for design purposes 300 j was taken as the energy requirement upon a power supply of battery or of generator type.

The space available for a battery-type power supply was of the order of 10 cu in. or 160 cu cm. This permitted a battery mass of about 250 g. The energy density of ordinary batteries ranged from about 10 to 30 whr per kilogram, i.e., 40 to 120 j per gram. Thus a minimum energy content of 10,000 j could be realized from a battery of acceptable dimensions. The total service demand of 300 j then represented only 3 per cent of the minimum expected total energy within a 60-sec period. This was clearly a tolerable class of battery service.

Dry Batteries. The ordinary carbon, zinc, ammonium chloride dry battery presented itself as the most readily available source of energy. It was the consensus, however, that considerations of delayed service and performance at low temperatures would significantly limit its usefulness.[2] Although these dry batteries could initially fulfill a pressing need with minimum delay, it seemed doubtful that they could be sufficiently improved as to be rendered completely satisfactory. The ultimate solution would lie in some basically superior power supply system.

Reserve Batteries. A reserve battery, in which the electrolyte was introduced just prior to use, could obviously meet the requirements of an indefinitely delayed service period. Furthermore, a battery of this type exhibiting excellent low-temperature performance had been developed by the Electrochemical Section of the National Bureau of Standards.[3] It used lead

oxide electrodes and a perchloric acid electrolyte. Some problems persisted, however, with regard to the introduction of the electrolyte.

Two alternatives existed here: electrolyte could be carried, separately packaged, within the battery assembly to be actively introduced upon application of some force due to projectile acceleration; or electrolyte could be packaged entirely separately from the battery and fuze, for introduction shortly before the insertion of the fuze into the projectile. The former required the development of novel battery designs to insure the rapid and proper distribution of electrolyte and the maintenance of operating, electrically discrete cells. The latter necessitated the development of special filling equipment and techniques which would be suitable for the uncontrolled conditions of field use. Also, the battery once made active could have a shelf life of approximately one day. After this period it would become useless, since recharging had proved unfeasible. Because of these disadvantages most engineering effort on electrolyte introduction was directed toward setback actuated systems. Although this method appeared possible in rocket and mortar applications, it was recognized that some externally triggered force would have to be provided in the case of bomb application where no setback would be present upon release.

The principal difficulties expected in the design of a reserve battery supply system lay in providing a high-voltage section consisting of a multiplicity of series connected cells using electrolyte from a common source. Here the problems of rapid thorough distribution of electrolyte and its subsequent retention without intermittent short circuiting became acute.

Battery Vibrator. Consideration was given the use of a vibrator high-voltage supply. Here a single low-voltage high-capacity battery could supply both filaments and the vibrator input. The design study of such a system was undertaken by the Washington Institute of Technology. Although their work indicated the general feasibility of this system,[203] it was not carried to the point of achieving a battery, vibrator, transformer, rectifier, and filter of the requisite small size.

Generator. The optimum solution of the power supply problem appeared to lie in the use of a mechanically driven rotary generator. Such a system offered several advantages, as follows:

1. An indefinite delay prior to use would not adversely affect its performance.
2. The generator would not be appreciably affected by temperature extremes.
3. The entire fuze unit, including power supply, could be shipped into the field assembled for use. No final assembly and test just prior to use would be required.
4. The rotating system of the generator could be coupled to suitable gearing to provide a mechanical arming and SD feature, if desired.
5. If the generator were wind-driven by the flight of the projectile, a considerable additional safety would accrue, since the power supply would be inert prior to the period of service.

Since the generator served merely as a converter rather than a storage source of energy, it could be quite small. A volume of 2 to 3 cu in. would suffice for an alternator of requisite power. The additionally available space of 8 or 9 cu in. could accommodate the rectifier-filter system and the prime mover for driving the generator.

Prime Movers for Generators. Two basically different conceptions of the prime mover were apparent: (1) a storage system which received an initial charge of mechanical energy prior to the service period, and (2) a wind-driven system continuously drawing energy from the windstream during the flight of the projectile. A rotating flywheel, a stressed spring, or a volume of compressed gas represent mechanical systems of the storage type. In any case a mechanical input of approximately twice the electrical requirements would be necessary, since efficiency of little more than 50 per cent could be expected from a miniature generator.

1. *Storage systems.* The necessary 600 j of mechanical energy can be stored in a flywheel of reasonable dimensions and at reasonable rotational speed. The basic expression for the energy of rotation, $W = \frac{1}{2}Iw^2$, becomes in the case of a simple cylinder of radius r, axial length l, density ρ, and rotational frequency f, about the axis

$$W = \pi^3 r^1 l\rho f^2.$$

[redacted]

Thus the rotation of a steel cylinder, $1\frac{1}{4}$ in. in radius and 1 in. in axial length, represents 2,600 joules at 40,000 rpm and 2,000 joules at 35,000 rpm. The required energy could be taken within this frequency range and a reserve content of 200 per cent would remain at frequencies above 20,000 rpm. The mass of this rotor is about 1.5 lb. The questions of adequate dynamic balancing and the design of bearings for the system arise as problems in development engineering, possibly difficult but certainly not insoluble.

The directly coupled flywheel-alternator system would have the advantage of permitting a completely sealed assembly. The fuze could carry external electric contacts by which high-frequency alternating current could be applied to the alternator for running it synchronously to charge the rotor to the proper frequency of rotation.

The system could be regarded as an a-c storage battery which delivers alternating current over the frequency range through which it has just been charged. It has the inherent disadvantage of requiring an electric charging source of adjustable frequency and reasonably high-power output, which must be available immediately before the launching of the fuzed missile. If the charging system fails, the fuze cannot be put into operation.

The operational disadvantages of field "charging" of rotors and the attendant equipment, coupled with the possibilities of engineering difficulties in massive fast-rotating systems precluded the serious pursuit of this method for driving generators. It nevertheless appears feasible, especially where the complete sealing of a generator powered fuze is required.

Energy content calculations indicate that a wound spring of adequate capacity would be prohibitively large. The energy content of a coiled clock spring is given approximately by

$$W = \frac{BTLS^2}{6E},$$

where B is the breadth, T the thickness, L the length of the spring, S the applied stress, and E Young's modulus for the material.

Since BTL represents the solid volume of spring material, the energy density of spring material is given by

$$\frac{W}{V} = \frac{S^2}{6E}.$$

In the case of spring steel stressed nearly to the elastic limit ($S = 2 \times 10^5$ psi and $E = 3 \times 10^7$ psi)

$$\frac{W}{V} = 25 \text{ joules /in.}^3 \text{ (approximately)}.$$

Assuming a 50 per cent efficiency of space utilization for the spring system, 48 cu in. are required for an energy content of 600 joules. This value is an order of magnitude too great for warranting its consideration as an energy source for the fuze power supply.

The use of a compressed volume of air for energy storage appears theoretically possible but requires extremely high pressures for holding the reservoir dimensions within permissible limits. Even assuming that the release is slow enough to approach isothermal conditions, a reservoir of 3 cu in. capacity would have to contain air initially at 100 atm to drive a 67 per cent efficient turbine for an adequate energy delivery coincident with a pressure drop to 16 per cent of the initial value, and this would correspond to an energy reserve of only about 80 per cent. Furthermore, this system of energy storage would introduce considerable engineering difficulty in the design of the high-pressure air flask, reduction valve and turbine system. It was not given consideration in the power supply development.

Another somewhat different storage method has been proposed by various participants in the program. This involves conversion of chemical energy to mechanical energy. A slow-burning powder might be used to provide the driving power for a generator. Detailed consideration of the method has not been made.

2. *Wind-driven systems.* For driving a power supply generator it appeared most advantageous to use a vane or turbine driven by the wind stream of the missile in flight. This side-steps the requirement of storing within the fuze sufficient energy for operation during its entire service period, but instead imposes the demand that the wind drive supply adequate

[redacted]

mechanical power to the generator at all times during its service period. Thus, the spread in air travel characteristics of various projectiles under various applications becomes a complicating factor.

A projectile moving with air velocity v and carrying a vane or turbine of efficiency e develops power in the turbine shaft with an attendant incremental force of drag f_d on the projectile.

Thus,

$$P = ef_d v.$$

The deceleration a upon the projectile of mass m is

$$a = \frac{f_d}{m} = \frac{P}{emv}.$$

For design purposes, P has a value of 10 w, so that an electric output of 5 w is available from a 50 per cent efficient alternator. The aerodynamic efficiency e of the vane or turbine will vary with airspeed and with load, but for all the situations of service to be met by the fuze it should exceed 50 per cent. Using these bases, the drag effect of the vane can be approximated for various projectiles of minimum sizes and at minimum airspeeds as follows.

Projectile	Mass, loaded (approx.)	Airspeed approximated minimum during service period of fuze	Deceleration due to drag of vane or turbine
Mortar shell M-43, no increment of charge	7 lb	150 fps	$0.14g$
Bomb M-30, release at 150 mph 2,500 ft air travel	100 lb	350 fps	$0.004g$
Rocket T-22, at extreme range	40 lb	500 fps	$0.007g$

The incremental drag due to a power supply vane system is obviously of no importance when compared to other sources of drag in bomb and rocket applications. In the case of the lightest mortar shells, it is evident that the drag may be great enough to cause a measurable shortening of range. However, even here the effect does not appear sufficiently serious to outweigh the operational and constructional advantages which the wind-driven system affords.

The system requires the design development of vanes or turbines suitable for use with the various bombs, rockets, and mortar shells. Other design problems on high-speed bearings, coupling elements, vibration isolation, etc., are inherent to the rotary alternator rather than the wind drive.

Selected Methods. Three methods of obtaining electric power for the fuzes were selected for intensive investigation. These were

1. Dry battery,
2. Reserve battery,
3. Wind-driven generators.

The first of these was selected for reasons of expedience and was used in the T-5 and T-6 fuzes. The third method was used in all later fuzes. The second method was pursued until it was demonstrated that wind-driven generators were practicable, at which time further work on reserve batteries was discontinued. Summaries of the work on these methods are given in the next three sections.

3.4.3 Dry Batteries

Dry batteries were selected for use in power supplies for early experimental fuzes and for production fuzes T-5 and T-6. They were selected because they were immediately available in quantity. Their limitations at low temperature or in delayed service were recognized.

Development work on dry batteries fell into two major categories: (1) the assembly and packaging of the best available cells into a mechanically suitable power supply unit, and (2) an electrochemical study of the individual cells with the aim of improving their characteristics.

The first battery packs were improvised assemblies of commercial miniature dry cells. These were to meet the urgent need of power units to permit proof testing of early experimental electronic assemblies of the fuze. Their design and operating characteristics were conventional and warrant no particular comment.

BA-55. One basic production dry battery pack was developed. This was made in two models: the BA-55, for powering rocket fuzes T-5 in plane-to-plane use, and the BA-75 for

T-6 fuzes in ground-to-ground use. The two models were identical mechanically and in battery make-up but differed in their electric arming and SD circuits, as shown in Figure 53. The electric arming and SD characteristics have been discussed in Section 3.3.

The BA-75 unit is shown in Figure 54. The plastic container is 2.60 in. in diameter and

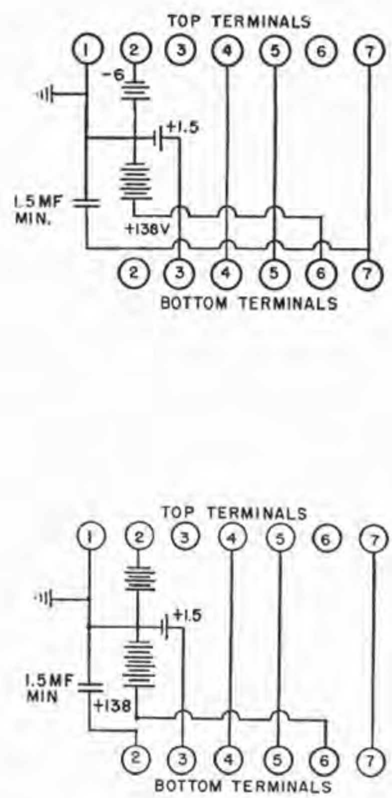

FIGURE 53. Schematic circuit diagrams for production battery packs. Top, BA-55 used in original T-5 fuze for plane-to-plane application. (Cf. Figure 12, Chapter 4.) Bottom, BA-75 used in T-6 fuze for ground-to-ground application, and with special switch in later T-5 fuze for plane-to-plane application.

2.31 in. in height. The pin sockets on the ends of the container provide contact with the electronic assembly and with the arming switch-detonator assembly. The weight of the battery is about 10 oz.

Individual cells of the battery pack were all of the zinc, carbon, ammonium chloride type with manganese dioxide depolarizer. The filament supply consisted of a parallel pair of zinc cup cells, of miniature (No. AA) dimensions. The plate and C-bias battery consisted of four series stacks of cake-type cells (National Carbon layer-built). The individual cakes were of rectangular cross section, 0.75 in. by 0.5 in., with rounded corners and were a little under 0.2 in. in thickness. The four stacks, totaling 96 cells, were arranged with the two cylindrical A cells in a circular array around a cylindrical noninductively wound paper capacitor of 1.5 mf capacity. The capacitor served as a reservoir for the detonator firing charge.

FIGURE 54. Battery pack, BA-75. At left is complete unit. At right is similar unit with end plate removed. Six stacks of layer built cells for B and C voltage, two cylindrical A cells, and detonator firing capacitor can be seen.

The electric characteristics of the BA-55 were as follows.

A voltage	1.50 min, open circuit, 20 C, new battery. 1.20 min, 3.3-ohm load for 30 sec, new battery.
B voltage	138 min, open circuit, 20 C, new battery. 120 min, 8,800-ohm load for 30 sec, new battery.
C voltage	6 min, open circuit, 20 C, new battery. Less than 2 per cent decrease from open-circuit voltage, 4-megohm load for 14 days, 20 C, new battery.

Temperature and Storage Properties. The BA-55 could operate at -15 C with less than 10 per cent decrease in these voltages, and after three months storage at 20 C could operate at 20 C or at -15 C within 10 per cent of its corresponding voltage output when new. The following table summarizes the performance of a typical BA-55.

Delayed service performance of dry batteries is much improved if the storage is at low temperature. Three years' storage at 9 C, two years, at 20 C, or six months' at 40 C causes about the same deterioration in dry batteries. In military field storage it could be expected

Test temp. (C)	Open-circuit voltage	Initial load voltage (3.3-ohm load)	Final load voltage (30 sec)
	New battery		
—15	(B) 134	120	110
	(A) 1.54	1.30	1.20
20	(B) 140	132	128
	(A) 1.57	1.42	1.39
	Three months' storage at 20 C (8,800-ohm load)		
—15	(B) 133	118	108
	(A) 1.51	1.29	1.20
20	(B) 138	128	124
	(A) 1.56	1.40	1.37

that at best temperatures of 20 to 25 C would be maintained. Thus protection against battery deterioration could best be provided by check on batteries immediately prior to use in the field.

In this connection the flash current delivered by the battery through a low (0.01 ohm) resistance deadbeat ammeter was used. The BA-55 at 20 C after three months' storage at 20 C would give a flash current of 8 amp for the A and 0.75 amp for the B section.

Fully adequate low-temperature service was inherently impossible with the ammonium chloride cells of the BA-55. Although the service was marginally acceptable at —15 C, it became completely impossible at about —25 C where the electrolyte froze.

Consideration of methods for keeping the ammonium chloride cells warm during service indicated no practical solution. Preheating was inconvenient and uncertain. The use of thermal insulation increased bulk where it could not be tolerated. Although it was found possible to heat the battery electrically by passing an alternating current through it up to the start of the service period, this was inconvenient and hazardous when applied to live fuzes.

Improved Dry Batteries. A dry battery power pack with satisfactory low-temperature characteristics appeared practical only with a basic cell which was superior to the zinc, carbon, ammonium chloride cell used in the BA-55. A study of electrolytes and electrodes was undertaken by the National Carbon Company.[199]

For low-temperature performance, calcium chloride was found the best of the several electrolytes. Acetylene black was found superior to conventional carbons for the positive electrode. Synthetic manganese dioxide was found superior to refined natural ore (Brazil earth) for the depolarizer. It was also established that several small and apparently insignificant assembly details required careful control for insuring quality performance at low temperatures.

When calcium chloride cells embodying these improvements were tested at —40 C, after 6 months' storage at 20 C, it was found that the A voltage fell to 1.1 v in delivering 170 ma for 15 sec, and that the B voltage fell to about 1.14 v per cell in delivering 1.25 ma for 15 sec. Both of these values were far short of the minimum requirements from the power supply and it was decided that the prospects of developing a satisfactory dry cell did not warrant further investigation.

3.4.4 Reserve Batteries[199]

As has been stated in Section 3.4.2, the perchloric acid cell had satisfactory service characteristics in all respects (including low-temperature properties) except for an extremely short delayed service period. The following table compares the perchloric acid cell,[3] the common dry cell, and the common lead cell in a few pertinent criteria.

	Perchloric Cell	Dry Cell	Lead Cell
Open-circuit voltage	1.8–2.2*	1.5–1.6	2.12
Output, amp-hr/kg	22	10	9
Output, whr/kg	39	12	17
Freezing point, degrees C	—60†	—25	—65
Flash current (miniature cells)	1.2 amp at —50C	0.01 amp at —30C	0.37 amp at —40C
Internal resistance (miniature cells)	1.0 ohm at —50C	150 ohms at —30C	5.6 ohms at —40C

* Depends on acid concentration.

† Minimum freezing point concentration gives —59 C, but this is lowered by the solution of lead perchlorate into the electrolyte.

[redacted]

The perchloric acid cell uses lead-lead oxide electrodes and sustains the following reaction during discharge:

$$Pb\,O_2 + 4HClO_4 + Pb \rightarrow Pb(ClO_4)_2 + 2H_2O + Pb(ClO_4)_2.$$

The perchloric acid cell differs significantly from the sulphuric acid-lead cell in that the lead perchlorate evolved on discharge is soluble in the perchloric acid electrolyte and does not plate out on the electrodes.

Developmental work on the perchloric acid cell was concentrated on the design of a reserve-type battery having the same outside dimensions as the BA-55. It was recognized that such a unit would not be usable with bomb fuzes,

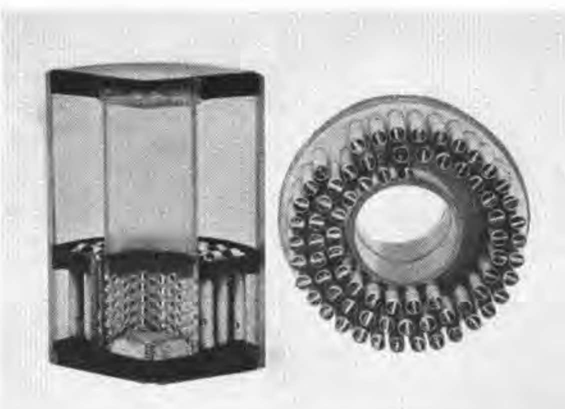

FIGURE 55. Reserve battery pack, first experimental design. This unit contained B cells only. Section of unit is at left. Glass ampule containing electrolyte occupied central space. Cell assembly, without hairpin plates, is at right. (Photograph by National Carbon Company.)

since it required setback forces for distributing electrolyte. However this appeared to be the only practical means of introducing electrolyte just prior to the service period, as necessitated by the short permissible service delay with perchloric acid cells.

The first experimental design of a reserve cell, built to the same dimensions as BA-55, is illustrated in Figure 55. This used cylindrical plastic tubes molded in concentric circles for housing the B cells. Nickel hairpin jumpers, having one end plated with lead, the other plated with lead oxide, formed the series of electrodes. Asbestos separators were mounted between electrodes in each cell. The acid was contained in a centrally placed glass ampule. This broke on setback and flooded the open ends of the cells. Subsequent ballistic forces being

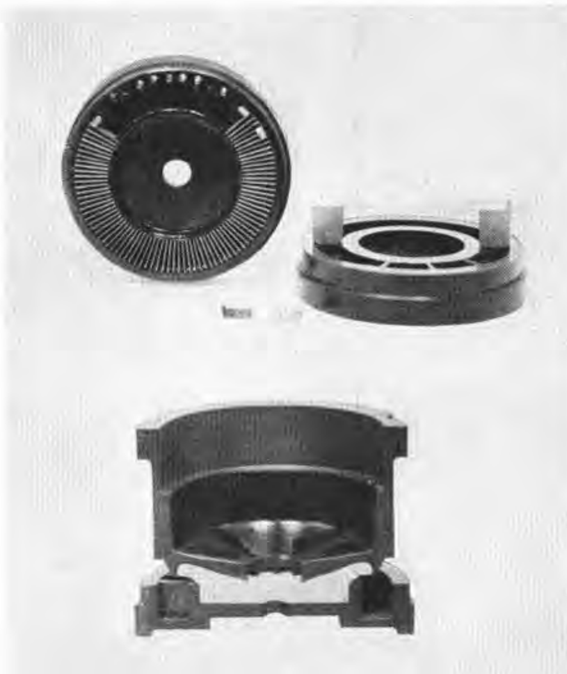

FIGURE 56. Reserve battery subassemblies. Top, radial plate B cell; bottom, ampule cavity and electrolyte distributor which was used in one experimental model. A cell was located at the bottom of ampule cavity. (Photograph by National Carbon Company.)

oppositely directed to those of setback drove the acid into the individual cells.

In proof tests of these batteries many voltage transients were present because of improper filling of the cells.

To improve this condition the radical revision shown in Figure 56 was tried. Here the B and C cells are formed by the many rectangular nickel plates which were molded into the plastic base, radially arrayed about the walls of a central plastic cup. As before, filling occurred upon ampule breakage. The acid passed through a fine wire mesh which removed broken glass into the flat cup A cell and overflowed the cup walls to fill the peripheral B and C cells. Retainers in the form of perforated Vinylite Krene, 0.008 in. thick, were used in each cell. It is notable that the nickel cell walls were plated

after being molded into the plastic base. With the cells filled with a solution of $HClO_4$ and PbO in water, a current of 10 ma for 8 min plated an adequate layer of Pb on one face and PbO_2 on the other. The nickel wall thus connects the B and C cells in series.

This model showed some improvement, but in field tests, used with fuzes on rockets, there were still an excessive number of malfunctions. These were undoubtedly due to voltage transients in the B supply. Although methods were proposed to improve the battery further, development was discontinued because the wind-driven generator (see Section 3.4.5) had been proved-in as a generally satisfactory source of electric power for fuzes.

3.4.5 Wind-Driven Generators

General. The wind-driven power supply consisted of three principal elements.

1. The driver (windmill or turbine).[h]
2. The generator.
3. The rectifier and filter.

These operated so interdependently, electrically and mechanically, that their design was necessarily evolved in close coordination.

The basic mechanical design of the entire power supply hinged upon a choice of method for transferring energy from the airstream around the missile to the rotor of a generator which was preferably located in the rear of the electronic assemblies of the fuze. One method was to mount a driver vane on the nose of the fuze and couple this to the generator by means of a central drive shaft extending through the electronic assemblies. A second method was to admit air through intake ports or scoops in the airstream, pass it through a duct to a turbogenerator assembly and thence to exhaust ports.

The first method received emphasis since the nose-mounted vane permitted the development of a generator-powered fuze embodying much of the basic design of the battery-powered T-5 fuze. Electronic assemblies could be revised to give clearance for a central drive shaft of small diameter. The inclusion of an air duct of adequate cross section would have required drastic revision. Additionally an awkward problem arose in exhausting air from a fuze mounted in the closed encasing can proposed for use. On the basis of a nose-mounted vane, the following fuzes were developed for use on bombs and rockets: T-50-E1, T-50-E4, T-89, T-90, T-91, T-92, T-51, T-30, and T-2004. Figure 57 shows a sectional T-51 fuze as typical of the mechanical design of fuzes of this class. The vane, bearings, central coupling shaft, and metal encased generator can be seen.

FIGURE 57. Fuze T-51 with section cut away. Nose-mounted vane and central drive shaft to generator rotor can be seen.

This discussion primarily covers the power supply of nose-mounted vane fuzes, since these were the ones produced in greatest quantity. However, other types using turbine drive are discussed in less detail.

[h] The driver for the generator on most generator-powered fuzes was a windmill mounted externally on the front end of the fuze. Generators on other fuzes were driven by turbines located in air ducts farther back in the fuze. The windmills were commonly called propellers because of their appearance. Most of the reference reports used the term propeller exclusively. The windmills were also extensively referred to as vanes, a term introduced by the Army. Both the terms, propeller and vane, were used to specify externally mounted drivers. Internally mounted drivers were referred to as "turbines." Occasionally the term impeller has been used (although probably incorrectly) to include both types of drivers, i.e., windmill and turbine.

Bomb fuze T-82 was developed as a complete departure from the nose-mounted vane. This used a central air duct from the nose to a turbogenerator at the base of the fuze. Peripheral exhaust ports were located in the plane of the turbine. No encasing can was required. Figure 58 shows a T-82 fuze sectioned to expose the air duct and turbine. A similar basic design was used in the miniature mortar fuze T-172. Peripheral air scoop, air duct, and exhaust ports were used in conjunction with a turbogenerator in bomb fuze P-4. (See Figure 48 of Chapter 4.)

Miniature mortar fuzes T-132 and T-171 and miniature rocket fuze T-2005 avoided both the central drive shaft and the air duct by locating a turbogenerator at the nose of the fuze. This was made possible by improvements in methods of balancing the turborotor with consequently quieter operation and by a redesign of the fuze antenna system. A sectioned T-132 is shown in Figure 42 of Chapter 4. Intake ports were holes punched in the face of the nose cap. Exhaust ports were in the side walls of the nose cap.

FIGURE 58. Fuze T-82 with section cut away. Central air duct to turbine can be seen. Generator was immediately below and directly coupled to turbine.

A design parameter of common importance to all elements of the power supply was the frequency range in which the rotor system was to operate. Low rotational speeds relieved bearing requirements, produced lessened centrifugal effects and vibration amplitudes, and were generally favorable mechanically. High rotational speeds increased the electric output from a simple generator and also simplified filtering because of the higher electric frequency.

However, the dominant factor in selection of the range of operating rotational frequencies was that the speed range be removed as far as possible from the frequency band to which the fuze amplifier responded. Within this band the amplifier was highly susceptible to electric noise, whether due to generator hum or to voltage induced by mechanical vibration. Amplifiers for various fuzes were peaked in the approximate range of 25 to 200 c, excepting the broad-band amplifiers of transverse antenna bomb fuzes, which had high gain up to 300 c (cf. Section 3.2). Since operation of the power supply was not feasible at rotational frequencies below 25 c, the design was planned with operation above 250 c (15,000 rpm) for longitudinally excited fuzes and above 333 c (20,000 rpm) for the bar-type bomb fuzes.

Constancy to about ± 5 per cent was required in the voltages from the power supply during a service period in which the airspeeds encountered by the vanes varied by as much as 3 to 1. The requisite voltage regulation was provided electrically by the addition of a mesh of proper impedance to the output circuit of an a-c generator. This obviated the requirement of incorporating aerodynamic or mechanical devices in the vane or turbine for regulating its rotational speed within close limits over a wide range of airspeeds. For all except the miniature fuzes it was sufficient that operation stay below an upper limit of about 40,000 rpm.

Vane and Turbine Requirements. With regard to the actual supply of power it was required that a vane or turbine under its operating load should maintain rotational speed within permissible limits for all airspeeds encountered between the times of arming and of fuze function. In most cases permissible rotational speeds ranged from 15,000 to 40,000 rpm for bomb and rocket fuzes, corresponding to airspeeds of 450 to 1,000 fps for bombs and 1,400 to 800 fps for rockets. Mortar fuzes permitted

higher peak values of rotational speed because of more compact and better balanced rotor assemblies.

However, the vane or turbine was also to serve as an integrator of air travel and a driver for the arming system of the fuze. This placed the additional requirement that vanes or turbines of a given type be extremely uniform in their rotational characteristics particularly over the range of airspeeds met during the arming period. This meant uniformity over the entire speed range since bombs armed at relatively low airspeeds, other missiles at higher airspeeds. Vanes or turbines for bomb fuzes carried the additional requirement that they develop sufficient torque to overcome the static load of the rotating system at an airspeed of 300 fps, minimum release speed, and yet develop less than this static torque at an airspeed of 200 fps which might be encountered in an open bomb bay.

The torques required from the vanes and turbines were small. The static torques of the rotating systems of the various fuzes in no case exceeded 3 in.-oz and averaged about 1.5 in.-oz.[151] Running torques were about this latter value.[48] At the minimum operating speed of 15,000 rpm this was equivalent to a mechanical input of 16 w, a figure consistent with the electric demand of about 7 w at an expected efficiency of 50 per cent, including frictional and other losses.

Vanes and turbines having the required operating characteristics were developed for quantity production as follows: vanes for bomb and rocket fuzes, moldings of phenolic plastic; vanes for bomb and rocket fuzes, punchings of sheet steel and Duralumin; turbines for bomb fuzes, aluminum castings and sheet steel punchings; turbines for mortar fuzes, aluminum alloy castings.

Vane and Turbine Design. Representative plastic vanes mounted on T-50 and T-51 fuzes are shown in Figure 59. These had three equally spaced blades with an effective diameter of 2.5 in. The blade surfaces were helicoids so that the vanes could be removed from a one-piece mold with a screw motion. Vanes having 6, 9, and 12 in. of lead (i.e., helical advance in one revolution) were used to provide the required assortment of rotational speed characteristics. These are shown in the curves of Figure 60 which also includes the characteristics of a typical metal vane.

FIGURE 59. Plastic vanes on bomb fuzes. Left, T-50-E1; right, T-51.

The metal vane is shown in Figures 19 and 20 of Chapter 4. These were 2 in. in diameter and carried 10 blades bent to angles of 55 or

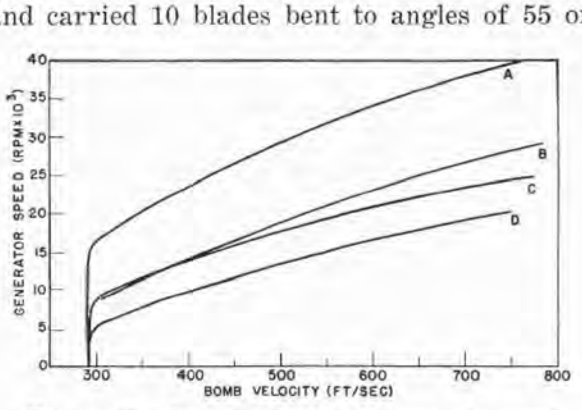

FIGURE 60. Rotational speed versus air speed for various vanes on T-50 fuze. A, plastic vane, 6-in. lead; B, Duralumin vane, 2-in. OD, 10 blades, 55-degree lead angle; C, plastic vane, 9-in. lead; D, plastic vane, 12-in. lead; A, C, D from field test data of reference 27; B from field test data of reference 28. All tests on M-81A bombs.

65 degrees relative to their original plane. The 55-degree metal vane was slightly faster than the plastic of 9-in. lead. The 65-degree metal was about equivalent to the plastic of 12-in. lead. Steel or Duralumin were used for the

metal vanes. Brass was satisfactory in operation but was too susceptible to deformation in handling. In some metal vanes, short radial ribs embossed along the center line of each blade at its narrowest section were found to increase the rigidity and eliminate the tendency toward blade flutter. (See Figure 19 of Chapter 4.)

Both plastic and metal vanes were used on bomb fuzes. A tabulation in detail is given in Section 5.5 on fuze data sheets. The operation of the vanes was affected by the airflow properties of the bomb with which they were used. They ran slower on larger bombs. The slowing was approximately over a 10 per cent range for the 100- to 500-lb bombs, another 10 per cent for the 1,000-lb and still another 10 per cent for the 2,000-lb bomb. This effect was of limited consequence for the ring-type fuzes which were designed for use on particular bombs.

However, bar-type fuze T-51 was designed for universal bomb service and used a broadband amplifier permitting 20,000-rpm minimum vane speed during service. Here a plastic vane of 6-in. lead was used. Operating speeds for this are shown in Figure 61. The bomb is

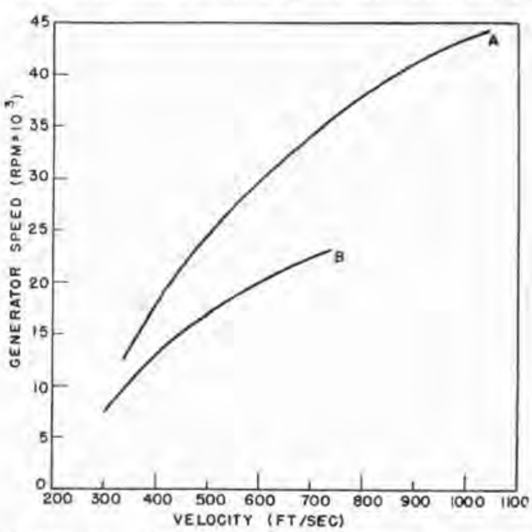

FIGURE 61. Rotational speed versus air speed for plastic vanes on T-51 fuze. A, 6-in. lead, M-81A bomb; B, 9-in. lead, M-57 bomb. A from field test data of reference 35. B from field test data of reference 30.

the M-81A, 260-lb fragmentation type. The curve for a 9-in. lead vane, also open-mounted on T-51, is shown for comparison. The extreme speeds of rotation for high-altitude release were a necessary concession to the attainment of high rotational speed at arming for low-altitude releases, particularly on larger bombs.

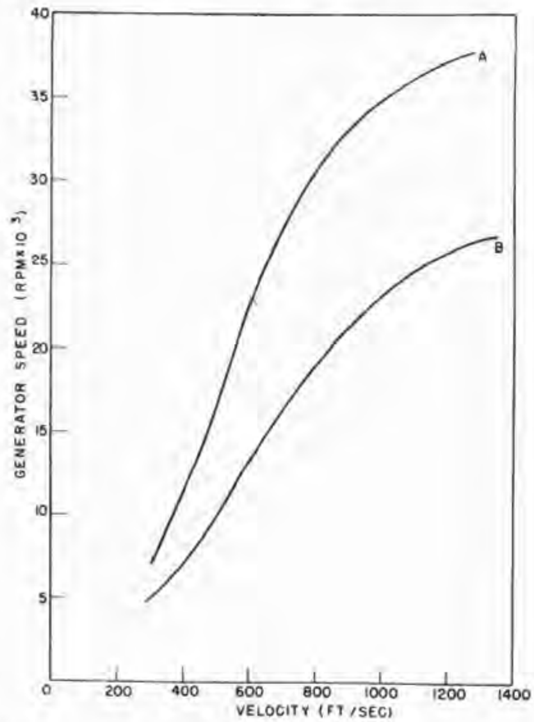

FIGURE 62. Rotational speed versus air speed for metal vanes on T-30 fuze. A, steel vane, 2-in. OD, 10 blades, lead angle 55 degrees; B, steel vane, 2-in. OD, 10 blades, 65-degree lead angle. A from field test data of reference 31. B from field test data of reference 32.

Metal vanes were used on rocket fuzes T-30 and T-2004. The 55-degree blade angle proved suitable for the range of airspeeds encountered. A typical speed characteristic of the 55-degree metal vane is shown in Figure 62. The characteristic of a 65-degree blade is included for comparison.

The T-82 turbine is shown in Figure 63. The die-cast aluminum base is 2 in. square and carries four fixed blades and four alternately placed lugs to which were affixed blades of steel clock-spring ribbon. In experimental development light springs were used to provide a regulating effect. At increased rotational speeds the blades were deflected toward a radial position both by centrifugal force and by the increased air impact. This reduced their effi-

ciency as driving blades and also caused them to throttle the flow from the adjacent fixed blade. However, in the production of T-82, possible regulation features were passed over in favor of the assurance of greater operating uniformity attainable with heavy springs.

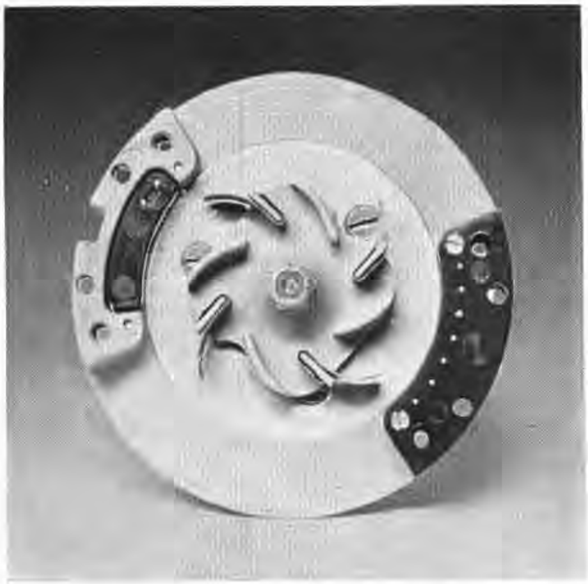

FIGURE 63. Turbine mounted on base assembly of bomb fuze, T-82.

Nevertheless, as is shown in Chapter 5, uniformity of speeds for the T-82 turbine was appreciably less than for other fuzes. A typical speed characteristic of the T-82 turbine is shown in Figure 64.

The turbine for mortar fuze T-132 was an aluminum casting in the form of a circular base $1\frac{3}{4}$ in. in diameter, carrying eight blades shaped as radial spirals. The speed characteristic of the turbine for selected extremes of firing parameters is shown in Figure 65. The curves show rotational speed against time of flight. Extremes of airspeed are approximately 2,000 and 200 fps.

Bearings. Bearings for the rotating system were called on for high-quality performance under severe operating conditions even though for a very short overall period. They were to support the vane or turbine and generator rotor at speeds to 40,000 rpm or faster. They were to take axial thrusts of as much as 15 lb from the airstream and radial thrusts of as much as 3 lb per 0.001 in.-oz of unbalance in the rotor at top speed. They were to introduce a minimum of vibration and electric noise into the electronic system.

Fuzes in final production used commercial miniature precision ball bearing assemblies or cushion-mounted Oilite bronze sleeve bearings in conjunction with accurately balanced rotary elements. Although the desirability of such bearing systems had been apparent since early in the program, precision ball bearings had not been immediately available in the necessary quantity nor had equipment suitable for rapid production balancing operations. Pending procurement of the former and development of the latter, fuzes of the T-50 and T-51 design were put into production, using improvised ball bearings and Oilite sleeve bearings. The success attained with these fuzes was due to the careful attention in production to dimensional tolerances on components and subassemblies of the

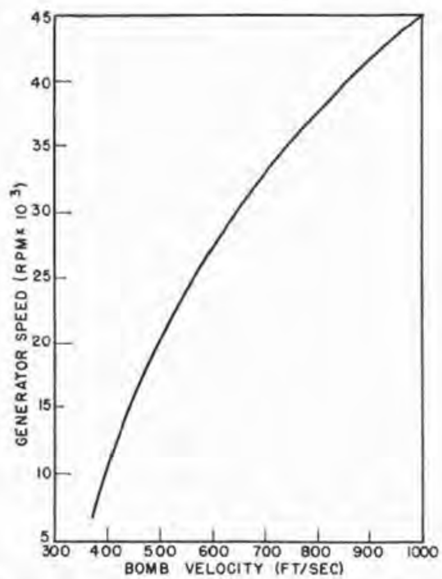

FIGURE 64. Rotational speed versus air speed for turbine of bomb fuze, T-82. Data from field test of reference 42.

mechanical system. This is discussed in Sections 6.4 and 6.5.

Fuzes using the nose-mounted vane required separate bearings for the vane and the generator rotor because of the 3-in. separation of these elements and because of the assembly problem involved. The vane bearing took the

thrust of the airstream and was necessarily a ball bearing. This was located in a strong r-f field from the oscillator and consequently was seated in a cylindrical brass or steel sleeve which extended downward to shield all moving parts of the bearing and the upper end of the coupling shaft. Vane bearing assembly may be seen in Figure 57. (Cf. Figure 18 of Chapter 4.)

The generator shaft took no axial load. In early production the bearings which supported it were Oilite bronze sleeves. Final production replaced these with precision ball bearings for reducing end play and mutation. A ball bearing generator is shown in Figure 70 of this chapter and Figure 27 of Chapter 6.

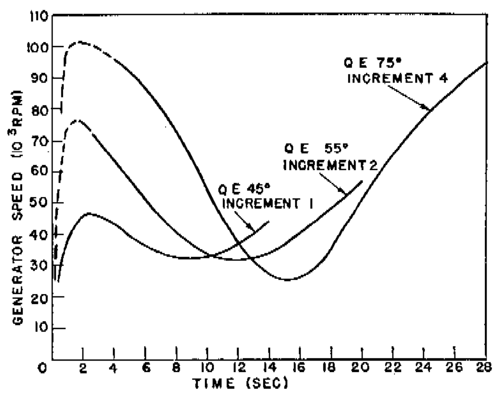

FIGURE 65. Rotational speed versus time of flight for turbine of mortar fuze, T-132. Curves are for M-43C mortar shell fired at quadrant elevations and with propellant charges as indicated.

The coupling shaft between the vane and generator transmitted a normal starting and running torque of no more than 2 in.-oz. When the fuze vane was freed from the block of an arming delay mechanism after high airspeed had been reached, the starting torque could approach 2 in.-lb. A metal shaft could not be used because of the noise and loss it introduced in passing through the r-f field of the oscillator. The required strength in the permissible small diameter was obtained by the use of rag-filled phenolic resin and other plastics. Even with a plastic shaft it was found necessary in the T-51 to electroplate a floating shield of copper inside the ⅜-in. sleeve surrounding the shaft to reduce the loss modulation which was introduced at rotational frequency.

In some vane bearing designs two ball-bearing assemblies were used. In this case both vane and generator rotor spun on established axes. The coupling shaft between their respective shaft ends was indexed on center pins which were fitted loosely enough to allow for the maximum tolerable misalignment. In other vane bearings a single ball-bearing assembly was used. This was mounted on a coupling shaft carrying the vane at its upper end and free at its lower end. The axis of the coupling shaft and vane was established when the free end was connected to the generator shaft.

Fuzes employing turbogenerators required only two bearings and no separate coupling shafts. Ball-bearing assemblies were used successfully with rotors which were not processed for balancing. Sleeve bearings and a single-ball thrust bearing were used with the precision-balanced turborotor of mortar fuze T-132. This is treated in detail in Chapter 4, which also includes a discussion of balancing methods and equipment.

Dynamic Balancing. In fuzes having a nose-mounted vane, unbalance in the vane was found most serious in producing vibration and electric noise. This was due to the location of the vane farthest from the supporting base, and the overhung mounting of the vane relative to its bearings. The generator rotors were of about the same weight as the vane (1 oz) but produced less noise because of their position near the base of the fuze and their mounting between two bearings. Satisfactory operation of a vane, either metal or plastic, was attained if its unbalance after mounting were made less than 0.001 in.-oz relative to its axis. The balancing of individual generator rotors was not found to be necessary, provided careful control of their dimensions were maintained.

Electric Design of Generator. Production model generators were alternators with stationary armature windings and rotary fields. Separate windings were used for supplying plate and filament voltages. Rotors were small disks of Alnico II or IV, magnetized with six peripheral poles alternately of reversed polarity.

The choice of this design rested on the following advantages:

1. It met the requirements of small size.

2. It required no slip rings or commutators.

3. Its use of a simple solid metallic rotor suited it to operation at high rotational speeds.

4. It facilitated the regulation of supply voltages over a wide range of rotational speeds by electric means, since the generated emf was directly related to rotational speed in both frequency and amplitude.

5. It was well adapted to quantity production by conventional methods.

Extremely scanty information was available in the technical literature on design principles for permanent magnet alternators. These had previously been used to a limited extent as industrial tachometers, as magnetos, and as special purpose generators.[214] The attainment of the power-to-volume ratio required for the fuze generator depended upon the use of relatively new magnetic materials and the extremely high rotational speeds involved.

The feasibility of the permanent magnet alternator was proved by exploratory investigations at the National Bureau of Standards.[4, 18] Early models of generator-powered fuzes were designed by the Westinghouse Electric and Manufacturing Company, and engineering design of the generator used in production fuzes was done by the Zenith Radio Corporation.[19]

1. *Principles of operation of the alternator.* The principles of operation of the permanent magnet alternator were easily derived for a highly idealized case and with several simplifying assumptions. The complete and rigorous mathematical analysis, including the effects of nonlinearity in the magnetic circuit and in the rectifier and hot filaments which constituted the coupled loads, was not attempted. If the solution were actually possible, its value is not consistent with the labor demanded. The idealized solution was fully adequate for evaluating the parameters of generator operation and for indicating the principles upon which a straightforward experimental development could be based.

A conventionalized diagram, applicable to the permanent magnet alternators which were used, is shown in Figure 66. The rotor, a six-pole permanent magnet disk, is located centrally within the magnetic stator which carries the armature windings. The magnetomotive force of the magnet passes flux through the stator to link each of the armature turns, and for each 60-degree rotation this flux is reversed in polarity. The resulting emf in the armature coils completes one electric cycle for each 120 degrees of rotation.

In the analysis which follows the six-pole alternator is considered as the equivalent of three series-connected bipolar alternators operating at three times the actual rotational frequency.

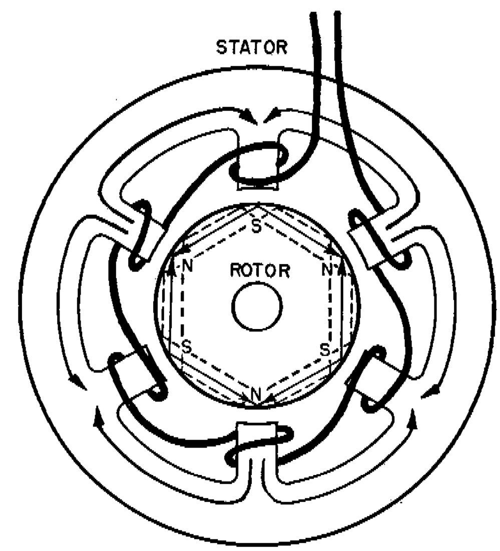

FIGURE 66. Diagram of six-coil generator. Rotor, stator, and armature windings are shown. Location of magnetic poles on rotor and flux paths are indicated.

Each bipolar alternator carries an armature winding of $(N/3)$ turns, where N is the total number of turns for the six-pole alternator. Each bipolar magnet develops magnetomotive force M equal to that developed by an adjacent pair of poles on the six-pole rotor. The permeance P_m for the rotor-stator flux linkage corresponds to that for an adjacent pair of poles in the six-pole alternator, i.e., two of the six rotor paths in shunt, two of the six stator paths in shunt, and two air gaps in series.

Experiment indicated that an alternator of this type delivered an essentially sinusoidal current I into a load containing only linear elements. The generating flux ϕ was then sinusoidal. The stator saw the rotor as a sinusoidally

[redacted]

varying mmf M of internal reluctance independent of angular position.

Thus, neglecting phase,

$$\begin{aligned} I &= I_{\max}\, e^{jwt}, \\ \phi &= \phi_{\max}\, e^{jwt}, \\ M &= M_{\max}\, e^{jwt}, \end{aligned} \tag{40}$$

where $w = 2\pi f$ (electrical) $= 6\pi f$ (rotational). The total flux linking an adjacent pair of armature coils with their pair of rotor poles is due to the rotor mmf and to the current in the coils themselves.

$$\phi = MP_m + \frac{0.4\pi NI}{3}(P_m + P_l), \tag{41}$$

where P_m is the effective permeance of the magnetic path through magnet, air gaps, and stator (two poles). P_l is the leakage permeance of the stator (two poles). N is the total armature turns.

The emf generated in the armature is

$$E = -kN\frac{d\phi}{dt}, \tag{42}$$

where k, a proportionality factor, is equal to 10^{-8}, and introducing equation (40),

$$E = -jkNw\phi, \tag{43}$$

combining with equation (41),

$$E = -jkNw\left[MP_m + \frac{0.4\pi NI}{3}(P_m + P_l)\right]. \tag{44}$$

The term E drives the current I through the internal resistance of the armature coils R_i, and the external load,

$$\begin{aligned} Z_0 &= R_0 + jX_0, \\ E &= I(R_i + R_0 + jX_0) \end{aligned} \tag{45}$$

combining with equation (44),

$$I(R_i + R_0 + jX_0) = -jkNw\left[MP_m + \frac{0.4\pi NI}{3}(P_m + P_l)\right],$$

$$I = \frac{-jkMP_mNw}{R_i + R_0 + j\left[\frac{0.4k\pi N^2 w}{3}(P_m + P_l) + X_0\right]},$$

$$|I_{\max}| = \frac{kM_{\max} P_m N_w}{\sqrt{(R_i+R_0)^2 + \left[\frac{0.4k\pi N^2 w}{3}(P_m+P_l) + X_0\right]^2}}. \tag{46}$$

In practice X_0 was always capacitative. At higher frequencies, the current approaches the limit.

$$|I_{\max}| = \frac{3M_{\max}}{0.4N}\,\frac{P_m}{P_m + P_l}, \tag{47}$$

which may also be written

$$|I_{\max}| = \frac{k\phi_{\max} N}{L_{\text{gen}}}. \tag{48}$$

From the foregoing it is apparent that with increasing frequency the alternator becomes a constant current source which will supply a constant voltage to a load of fixed resistance. The limiting maximum value of current is, by equation (48), directly proportional to the rotor flux linkages with the stator turns and inversely proportional to the total generator inductance. By equation (47) the limiting current is increased by increase in M (the rotor mmf) or by increase in P_m (the rotor path permeance), but is decreased by increase in N, since this gives a square law increase in the inductance and only a first-power increase in rotor flux linkages.

While leakage permeance contributes no power producing flux linkage, it is seen from equation (46) to be as effective as rotor permeance in increasing the rate at which current constancy is approached with rising frequency. For increasing this rate R_0 and R_i should be held to minimum permissible values.

The internal resistance R_i contains three series components: the resistance of the stator turns, the reflected resistance of stator and rotor hysteresis loss, and the reflected stator and rotor eddy-current loss. The reflected resistances both increase as the square of the frequency.[217] It is obviously important to minimize them, since they represent power losses which impair rather than help regulation of load voltage with frequency.

In practice the design of the magnetic circuit of the generator was worked out to provide some excess of power at the minimum rotational speed. Subsequent adjustment of coil turns, bleeder circuit components, and the rotor magnet strength achieved the proper output voltages and regulation characteristics.

2. *Voltage regulation.* The permanent magnet alternators of production design were es-

[redacted]

sentially self-regulating with frequency, provided they were heavily loaded. However, the voltage regulation was improved by the addition of capacitative reactance to the load circuit.[22] This was done by either a series or a shunt connection. The methods were used individually or in combination.

Series connection may be evaluated from equation (46) of the preceding section. With X_0 negative the total reactance goes to zero at some frequency and the generator current is limited entirely by the circuit resistance. The value of C could be chosen to produce current resonance just at the lowest operating frequency so that transition into current, and voltage, constancy was made more sharp. If C were too small for the values of L and R, the high Q of the circuit at resonance caused overregulation. With too large a value of C the entire effect was lost.

Shunt regulation was obtained by shunting the generator output with a mesh consisting of a resistor and a capacitor in series. The values were so chosen that the mesh loaded the generator only slightly to the threshold operating frequency but loaded increasingly with increasing frequency. Analysis indicated that this circuit was inherently overregulating if C were too great and R were too small.

The discussion to this point has considered the voltage regulation of a single supply voltage from a single generator winding, the high-voltage supply. The filament winding was regulated, however, by reaction from the high-voltage regulation since it was closely coupled to the high-voltage winding with an iron core in common. The coupling was not 100 per cent and consequently the cross-regulation was not perfect. It was usually necessary to maintain B voltage with slight overregulation in order to develop adequate A regulation. Early development model generators achieved good cross regulation by locating the coils in the flux field so as to produce a phase asymmetry in their voltages.[22] This was abandoned in production models to simplify the mechanical design of the generator.[19] The C bias voltage was inherently regulated with the B supply, since it was developed as an IR drop in the plate current circuit.

Representative A and B voltage rotational speed regulation characteristics are shown in Figure 67. Shunt regulation circuits for fuzes T-50, T-51, and T-30 are shown in Figures 75, 76, and 77. Series regulation as used in fuze T-132 is shown in Figure 78. Here the series

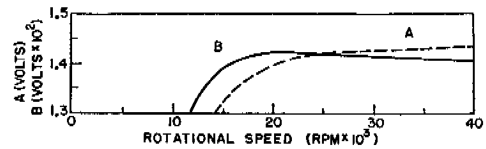

FIGURE 67. Plate and filament supply voltages versus rotational speed of generator in T-51 fuze. Dashed curve A is for filament voltage. Solid curve B is for plate voltage. (Reference 209.)

capacitance was provided by the capacitors of the bridge-type voltage-doubling rectifier. Compound regulation, i.e., shunt and series capacitance, was used in fuze T-82 as shown in the circuit of Figure 79.

3. *Rotor design.* The magnetic rotor has been considered in the case of an ideal generator as a source of sinusoidally varying mmf having constant internal reluctance. The rotor of an actual generator does behave much in this manner, as can be seen by reference to Figure 68, the major hysteresis loop for the magnetic material constituting the rotor.[68] A rotor in its matching magnetic stator (such as is shown in Figure 66) operates on a minor hysteresis loop 4-5 while in rotation. The minor loop lies within the third quadrant of the major loop specifically located according to the magnetic preconditioning of the rotor. Its slope in any event is very nearly equal to that of the major loop at point 2.[215] The rotor, for any angular position, has an operating point at the intersection of the minor loop with an appropriate shear line. The shear line is a radius vector whose negative slope equals the ratio of permeance of the space occupied by the magnet to permeance of its external flux path. The end points of the minor loop lie on the two shear lines 0-6 and 0-7, which represent respectively maximum external permeance (the angular position for alignment of rotor and stator poles) and minimum external permeance (the mid-position of complete misalignment).

The axis of the minor loop 4-5 must pass through point 3, which is the intersection of the major loop with shear line 0-3. Shear line 0-3 corresponds to the minimum external permeance to which the magnet has been exposed. Where rotors have been removed from a magnetizing jig and transferred openly to the generator, 0-3 corresponds to free-space permeance and is the strongest demagnetizing force the rotor can encounter except for the application of a demagnetizing field from external current turns.

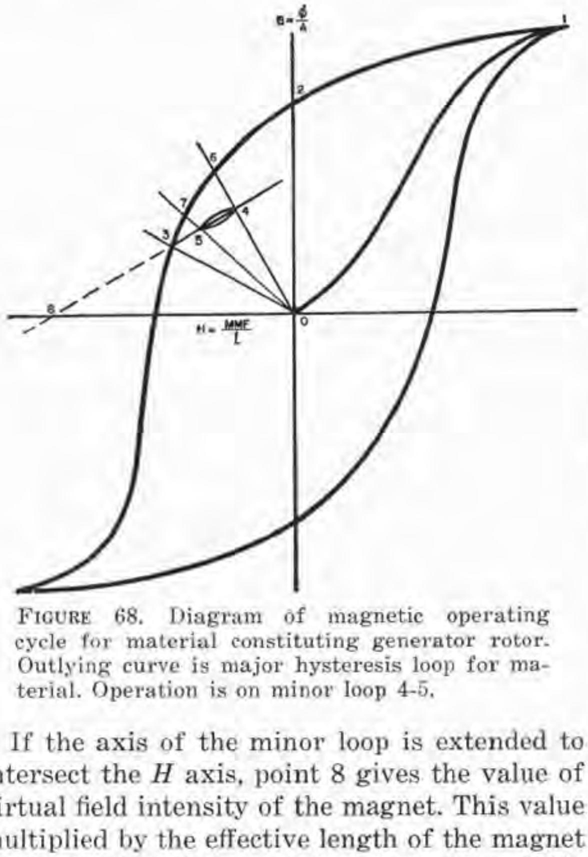

FIGURE 68. Diagram of magnetic operating cycle for material constituting generator rotor. Outlying curve is major hysteresis loop for material. Operation is on minor loop 4-5.

If the axis of the minor loop is extended to intersect the H axis, point 8 gives the value of virtual field intensity of the magnet. This value multiplied by the effective length of the magnet is the M (maximum mmf) of equation (40). The slope of the axis of minor loop 4-5 defines μ_{eff}, the effective internal permeability of the rotor material. Together with the effective length and cross section of the rotor magnet this determines the internal reluctance of the magnet. This reluctance, the air gap reluctance, and the stator reluctance determine P_m (rotor path permeance for two adjacent poles) of equation (41).

For a rotor advance of 120 degrees the stator sees one full cycle of sinusoidal mmf but the rotor meanwhile twice traverses its unidirectional loop of operation. At point 5 in the loop the stator sees 0 mmf. At point 4 it sees a maximum mmf, either positive or negative according to the sense of rotor-stator pole alignment. The minor loop 4-5 defines rotor operation in the unloaded generator. With a load applied the rotor magnet is linked by armature current turns and is subjected to an additional demagnetizing force which shifts the loop down and along its axis by an amount dependent upon the phase and magnitude of the load current. The use of high coercivity magnetic material, such as an Alnico, is indicated if this effect is to be minimized.

In the design of the generator, spatial considerations dictated a maximum rotor diameter of approximately 1 in., which, for six-pole magnetization, set 0.5 in. as the length of each magnet. The minimum radial gap between rotor and stator poles for quantity production was set at 0.010 in., with gaps of 0.020 in. or more considered preferable. The maximum permeance shear line could be roughly estimated to have a negative slope of 25 in the case of the 0.010-in. gap, and 12.5 in the case of the 0.020-in. gap. Reduction of the effective air-gap area by reduction of stator pole thickness would further reduce the slope of the shear line.

Permanent magnet steels are used most efficiently at an operating point which puts their BH product at a maximum. This corresponds very nearly to operation with a shear line having negative slope equal to the ratio of residual induction to coercivity for the material.[215] For Alnico I this ratio is 16; for Alnico II, 13; for Alnico IV, 7. All were tried as rotors during the experimental program. Alnico IV proved magnetically superior and was used universally in the production generators. Cast rotors of Alnico IV also proved mechanically stronger than cast rotors of other Alnico types.

Salient pole rotors, like that in the development model generator of Figure 69, were tried as a means of increasing the effective length of the rotor magnets. When magnetized by conventional means, the internal magnetic paths apparently jumped the tooth spaces between poles, so that the benefit was not realized.[45]

Since they were mechanically weaker and less well balanced than the simple disk rotors, their use was abandoned.

The proper selection of the A to B turns ratio for the armature coil permitted the supply of precisely proportioned A and B voltage through average rectifiers to nominal loads. The B/A ratio could be held within tolerable limits (7 per cent) when rectifier, filter, and load components were allowed their contingent of spread. However, the variation of magnetic strength in individual saturated rotors, although it produced no effect in the B/A ratio, caused a spread of over 20 per cent in the common level of the voltages.[68] This spread was eliminated by designing the generator to deliver voltages of the required or greater value with all saturated rotors except a small percentage of the weakest. After the assembly of the entire power supply the rotors were demagnetized individually to provide the proper operating voltages.

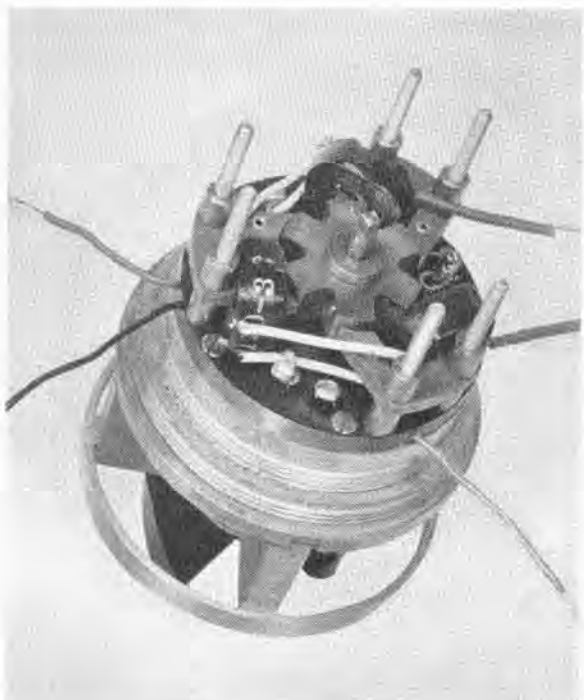

FIGURE 69. Early experimental generator. Three-section stator and thick salient pole rotor are shown.

The demagnetizing field could be applied by external coil or by the passage of alternating or direct current through the armature winding. By reference to Figure 68, it is seen that the demagnetizing force moved the operating point of the magnet along its minor loop to the intersection with the major loop at point 3. Further demagnetizing force moved the operating point down the major loop. When the demagnetizing force was removed the magnet assumed a new minor loop on an axis parallel to, but below, its former axis and with operating end points on its former shear lines.

The demagnetization produced a stabilization of the magnet against the effects of demagnetizing forces from momentary overload, etc. The farther displaced its operating minor loop from the major loop the greater was the margin of protection. Since the great percentage of production generators required strong demagnetization, their operation in service showed no fatigue effects nor pole shift.

Production Models. The production model of the basic six-coil generator, for use in nose-mounted vane-type fuzes, is shown in Figure 70. An Alnico IV rotor in the form of a disk, 1.020 in. OD and 0.25 in. thick was used. The stator core was a stack of five punched laminations of 26 gauge (0.0188 in.) low-silicon audio-transformer steel, C grade. The radial air gap between rotor and stator was 0.010 in., which was maintained at $+0.0030$ to -0.0015 in. in production by careful control of the dimensions of the die cast housing and its seats for the ball bearing assemblies. The maximum dimensions of the housing were 2.75 in. for the diameter

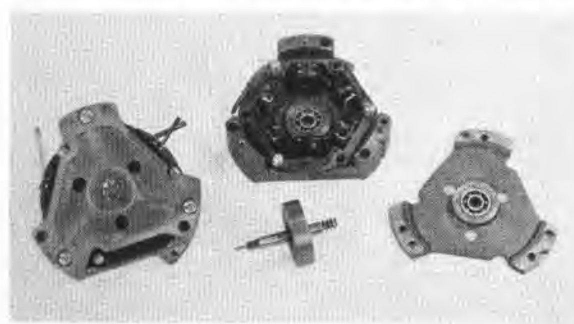

FIGURE 70. Production model six-coil generator and principal components. Assembled generator is shown at left. Rotor, mounted stator, and cover plate are shown at right.

and 0.75 in. for the thickness, exclusive of shaft extensions.

Although three coils would have been adequate for intercepting all the flux of the magnetic circuit, small coil dimensions were possible when six were used. This permitted a reduced length of mean turn and a thinner generator assembly. Each coil was wound on a plastic bobbin with a high-voltage winding of 1,940 jumbled turns of No. 41 AWG enameled copper wire. Over this was the filament winding of 13 turns of No. 28 AWG Formvar-coated copper wire. The six B and the six A windings were connected respectively in series.

In operation the generator developed open-circuit voltage in the plate winding which increased linearly with rotational speed to approximately 1,000 v at 40,000 rpm. This indicated the absence of appreciable core loss in the magnetic circuit.[19] The power output into rated loads with an average saturated rotor was approximately 10 w at 15,000 rpm. This provided an adequate margin for accepting a high percentage of rotors after voltage had been standardized by demagnetization.

A second production-model generator for use in the nose-mounted vane assembly was the single serpentine coil model shown in Figure 29 of Chapter 6. This was developed as a means of reducing the production complexity of the six-coil generator by the use of a single pliant bundle wound coil which could be intertwined about the stator pole extensions. The coil was impregnated with varnish and baked in its final deformed position on the stator. The flux linkage with the serpentine coil is identical with that of the six-coil generator, each of three circumferential sections of the single coil being linked by a complete flux path in the one case and each of three pairs of series coils being linked by a complete flux path in the other.

The rotor was an Alnico IV disk, 1.178 in. OD and 0.25 in. thick. The stator core was a stack of seven laminations of 0.075-in. low-silicon transformer steel, C grade. A rotor-stator air gap of 0.020 in. was possible here by virtue of the increase in rotor diameter and in thickness of the stator pole face. The generator was assembled into a case consisting of two drawn brass cups. Maximum dimensions were approximately 2.85 in. for the diameter and 0.75 in. on the axis, exclusive of shaft extensions.

The serpentine coil included 2,700 turns of No. 39 AWG Formvar-coated copper wire for the B winding and 21 turns of No. 28 AWG Formvar-coated copper wire for the A winding. The electric operating characteristics were essentially equal to those of the six-coil generator.

Miniature mortar fuze T-132 used the standard six-pole generator with mechanical modifications for adapting the stator assembly to a maximum 2 in. OD and for incorporating the rotor into a single unit with the driver turbine. This is shown in Figure 42 of Chapter 4. The reduction in OD of the stator assembly was effected by removal of peripheral sections of the lamination stack which had been used for mounting the stator. The magnetic operation of the stator was not significantly affected. The rotor was reduced in diameter to 1.000 in. with a resultant increase in radial air gap to 0.018 in. The consequent reduction in generator output relative to the standard six-pole model was corrected by appropriate revision of the rectifier and load circuits.

In a similar way the miniature mortar fuze T-171 adapted the serpentine coil generator to turbogenerator use. The rotor and the stator lamination stack were in this case identical to those used in T-132. For forming the serpentine coil on a small radius and holding axial thickness to the permissible maximum the winding was distributed in two coils. The resulting double serpentine is shown in Figure 35 of Chapter 4 in comparison with the single-coil model.

The generator for miniature mortar fuze T-172 used three coils and a multisection stator core in a novel design evolved by the Zenith Radio Corporation. The production model was superficially similar to the development stator assembly[1] shown in Figure 45 of Chapter 4.

The production stator was a 0.125-in. stack of fine transformer steel laminations in the

[1] This development stator shows the pole piece ring as continuous. Magnetic isolation of the six "pole pieces" was effected by shading the ring at the six intermediate points with copper straps. The production model was superior to this model both in operational characteristics and in simplicity of construction.

shape of a ring 2.00 in. OD and carrying three radial magnetic paths with wide pole faces on an ID of 0.820 in. Three additional radial elements with wide pole faces were preassembled as stacks, upon which coil bobbins were molded and the coils wound. These coil-on-core assemblies were riveted into the stator ring to complete the stator magnetic circuit. A retainer ring carrying six lugs was used to brace the pole piece "ring" and index adjacent poles for circumstantial air gaps of 0.050 in. The retainer was a nonmagnetic alloy (Advance) of high resistivity for minimizing eddy-current loss.

The rotor was an Alnico IV disk, 0.780 in. OD and 0.250 in. thick. This provided a rotor-stator air gap of 0.020 in. The large stator pole width permitted a reasonably steep shear line for rotor magnet operation even with the small diameter rotor. Consequently, the electric characteristics of this generator were similar to those of other mortar fuze generators.

Bomb fuze T-82 used a turbogenerator seated in the base casting which threaded into the fuze well. (See Figure 58.) This limited the OD of the generator to 1.33 in. and its axial length to about the same value exclusive of shaft extensions. A satisfactory design to the space requirements was achieved in conjunction with a single-bobbin wound coil by a drastic revision of the magnetic circuit.

The serpentine coil generator used a magnetic circuit (involving three pairs of poles) which was restricted to one plane. The winding was deformed from the plane to thread alternately over and under adjacent stator poles. Alternately the winding could have been held in one plane and the magnetic circuit folded around the coil. The T-82 generator, which is shown with its disassembled components in Figure 71, used a magnetic circuit which folded around the coil and brought six stator pole pieces of alternate polarity into alignment with those of a magnetic rotor located coaxially at the end of the coil. Despite its unconventional magnetic circuit design, the T-82 had an electric and magnetic operating cycle identical with that of the serpentine or six-coil generator.

The principal components of the magnetic stator were a cup with three extended poles, a spider with three extended poles, and an annular magnetic core which linked the cup and spider through the center of the coil. The cup and spider were drawn from a 0.062-in. sheet of 47 per cent ferronickel. The core was turned from first quality ingot iron.

FIGURE 71. T-82 generator and principal components. Assembled generator is shown at left. Grouped at right are spider, coil, core, rotor, center stud with upper bearing, cup with cover plate.

The success of this generator design hinged on the use of 47 per cent ferronickel in the magnetic stator. It was used unannealed after drawing and still had extremely high permeability and low hysteresis losses at the low (2,500 gauss) flux densities encountered. In addition, its high resistivity was of extreme importance in reducing eddy-current losses to a negligible value in an unlaminated assembly.

The magnetic rotor was a disk of Alnico IV, 1.140 in. OD and 0.400 in. thick, magnetized with six peripheral poles. The radial gap between rotor and stator was 0.030 in. The large air gap gave a very low slope to the shear line for the rotor magnet with consequent poor utilization of the magnet volume. This necessitated the use of the thick rotor. The coil bobbin carried a jumble winding of 3,800 turns of No. 42 AWG enameled copper wire for the high-voltage supply and over this 28 layer wound turns of No. 28 AWG Formvar copper wire for the filament supply.

Because of its long magnetic circuit, the T-82 generator was characterized by high leakage inductance which limited the power available into the operating load to 7 w with a saturated rotor at 20,000 rpm. For this reason a compound regulating circuit was used to assure

adequate operating voltages when marginally weak magnetic rotors were used. The high leakage inductance also gave a large value of voltage-load regulation. In consequence the T-82 rotor was demagnetized to standard output voltage after final assembly of the fuze when the generator operated into its actual load.

A novel experimental generator was developed as a standby for use in the T-82 fuze-well mount. This used a stator of stacked laminations and a coplanar coaxial disk rotor of small diameter. However, the stator carried a single distributed winding of 90 turns of No. 20 copper wire. By use of a rotor 0.5 in. thick and an air gap of 0.010 in. a power output of 13 w at 20,000 rpm was delivered at 6 v. This was fed to an externally located miniature transformer whose secondaries supplied the required A and B voltages.

The turbine-driven generator of the P-4 experimental bomb fuze differed both in design and operating principle from other generators.[204] In this case both permanent magnet and armature coils were stationary. The emf was developed by passage of pulsating flux through the coil core under the control of a highly permeable salient pole rotor which while in rotation served as a periodically varying reluctance in the magnetic circuit.

The general assembly can be seen in Figure 72. The two coils carrying distributed A and B windings were mounted on the legs of a U-shaped lamination stack which was eccentrically located relative to a laminated rotor having seven salient poles. A yoke containing the permanent magnets linked the base of the U-shaped coil core to the rotor through a wide-angle pole face which saw one pole of the rotor for any angular position. The two poles of the coil cores were designed for an angular separation of one and one-half teeth of the seven-pole stator. Thus the rotor in rotation alternately passed unidirectional flux through the two coils at a frequency of 7 cycles per revolution and with 180-degree phase difference. The coils were series-connected to deliver alternating current at 7 times rotational frequency.

With its 36-blade 45-degree blade-angle metal turbine the generator operated at 9,000 to 30,000 rpm for airspeeds of 300 to 1,000 fps, so that the generator emf was in the range of 1,050 to 3,500 c. In this range the generator was regulated by its own inductance and no external regulation circuit was required. Because of the use of stationary magnets it was possible to effect normalization of output voltage by use of an externally adjustable magnetic

FIGURE 72. P-4 power supply, partly disassembled. Stator and its two armature coils can be seen at right edge of generator assembly. (Photograph by Bell Telephone Laboratories.)

shunt. The voltage and power delivered by the P-4 generator was approximately equal to that delivered by the rotating magnet designs.

3.4.6 Rectifier System

A rectifier was required for converting the alternating high-voltage output of the generator to direct current for supplying the plate circuit of the fuze. Filaments could be operated on alternating current directly from the generator A winding as discussed in Sections 3.1 and 3.2. The B-supply rectifier was necessarily of an electronic type, since the intermittent contacting of mechanical rectifiers was an intolerable source of r-f disturbance. Thermionic diodes and blocking layer cells, both selenium and copper oxide types, were considered as rectifiers.

Full-wave rectification was a virtual necessity in order to minimize ripple and obtain a satisfactory voltage conversion from such a high-impedance source as the generator B winding. Three types of full-wave connection were possible: full wave with two diodes work-

ing from a center-tapped supply, two diodes in a bridge or cascade voltage doubler, four diodes in a full-wave bridge.

Vacuum-Tube Rectifiers. No existing tubes of the subminiature class were readily suited to this service. Triodes NR3 and NS3 had adequate current capacity and inverse voltage characteristics.[62] However, they were required in multiple, and separate electrically isolated filament supplies were required because the cathodes were directly heated.

Blocking Layer Rectifiers (Selenium and Copper Oxide). Selenium or copper oxide cells rectify by preferential conduction in one sense of direction across an interface, between selenium and iron in the one type of cell and between copper and copper oxide in the other. Having no filaments, assemblies of these cells could be used in any of the full-wave circuits without need for isolated filament supplies. Because of this simplicity of application and the indications that a selenium rectifier cell of acceptable characteristics was feasible,[216] extensive effort was directed toward the development of such a rectifier and the effectuation of facilities for its production in quantity. This program, which was carried on with close coordination between the National Bureau of Standards and the several manufacturers, was largely a program of production engineering and quality control. It is discussed in more detail in Chapter 6.

The selenium cell shown in Figure 29 of Chapter 6 was developed as the basic component for all the power supply rectifiers. An assembly of 20 cells in a full-wave bridge is also shown. Other production assemblies were a 24-cell full-wave bridge and a center-tapped 20-cell stack for use as a bridge doubler. The individual cells were 0.28 in. in diameter and 0.030 in. thick. The effective rectifying zone was a central circular area of 0.075 sq in. A typical static voltage-current characteristic for the selenium cell is shown in Figure 73. For comparison the static characteristics of a type-AQ copper oxide cell of similar dimensions is included.

Although the cells had nonlinear characteristics for both forward and reverse current, values of effective forward or reverse resistance could be defined for any static operating point as the simple ratio of E to I. Similarly a value of effective resistance could be ascribed to a group of several series-connected cells for specified operating conditions. A full-wave bridge (cf. Figure 75) comprising four symmetrical arms, each arm of forward resistance R_f and reverse resistance R_b, could be approximately represented[62] by a full-wave bridge containing four ideal rectifiers, having a resistance $2R_f$ in series with the load and a resistance $(R_b/2)$ in parallel with the source.

This clearly shows the significance of both forward and reverse characteristics of the cells in determining the output voltages, particularly when a high source impedance is used. In the fuze power supply the B winding was a high-impedance source tightly coupled to the A supply. Here a decrease in the effective R_b of the bridge loaded the B winding more heavily and by reflection loaded the A winding. Conse-

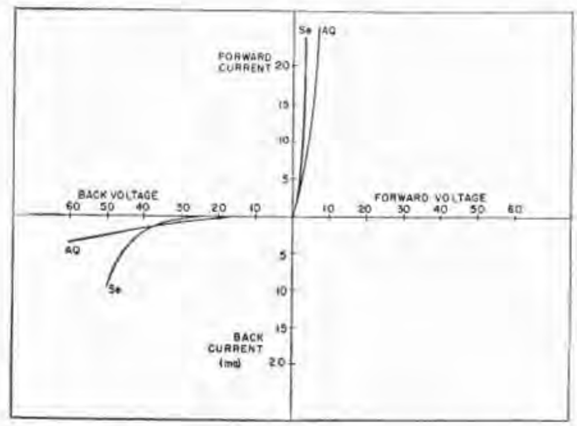

FIGURE 73. Static characteristics of blocking layer rectifier cells, 7 mm in diameter. Curve Se is for selenium cell. Curve AQ is for type AQ copper oxide cell. Data from reference 64.

quently both A and B voltages decreased. An increase in R_f decreased the B voltage but lightened the load on generator so that the A voltage increased.

In the development study which was primarily the statistical analysis of extensive experimental data, measurements were made on the static characteristics of individual cells. Rectifiers assembled from cells of known characteristics were then studied in dynamic service, i.e., operating with typical generators under typical

loads. The resulting correlation[65] between static cell characteristics, observed under selected reference conditions, and operating power supply output voltages is shown graphically in Figure 74. The limits within which individual cells were classified for acceptability are shown by dashed lines in the figure.[15]

Subsequently a dynamic test on 60 c alternating current was evolved[68] with proper limits for the assembled rectifier bridges. It was found that statistical assurance of an acceptable bridge resulted from a distribution of 75 per cent or more of the individual cells in Class A, 95 per cent or more in Classes A, B, and C, with no open cells in the remainder.

selenium cells output voltages could be maintained within tolerable limits[15] over the required operating range of −40 to +60 C.[192] Copper oxide cells were not suited to use in the power supply because both forward and reverse resistances showed a marked inverse variation with temperature. This resulted in the development of excessive A voltage at extreme low temperature.[64]

3.4.7 Filter and Detonator Firing System

The term filter system was used broadly to include the several elements of resistance and

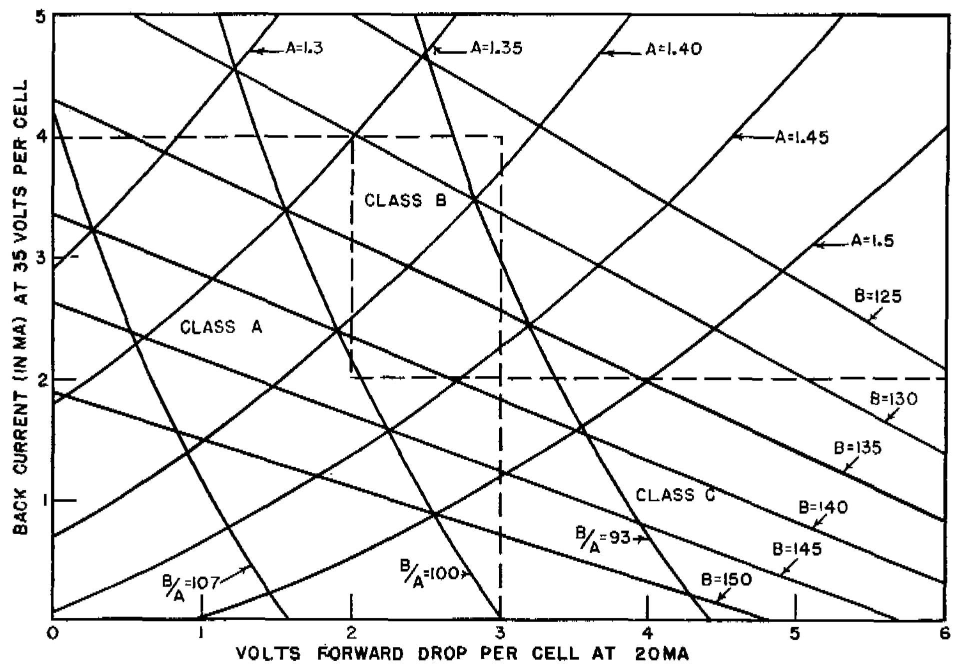

FIGURE 74. Power supply output voltages as function of static characteristics of selenium cells in the rectifier. Curves A refer to indicated values of filament voltage. Curves B refer to indicated values of plate voltage. Dashed lines indicate acceptance limits for cells of Classes A, B, and C. The diagram is from reference 68.

Selenium cells had appreciable temperature dependence. The reverse resistance was a maximum in the 20 to 30 C range and decreased for higher or for lower temperature.[206] The forward resistance varied in approximately inverse relation to the temperature. Reverse resistance decrease, particularly at lower temperatures, was of primary importance in affecting the output voltages from the power supply.[69] With

capacitance interposed between the rectifier and the power-supply output terminals. The system served the following purposes: reduction of ripple voltage in the plate supply, development of the required C bias potentials, storage of charge for firing the detonator, provision for adjustment of output voltage by the insertion of selected resistors, and provision of an electric arming delay where required.

[redacted]

The power supply filters in all cases employed an input capacitor followed by a single L section of series resistance and shunt capacitance. Since the input capacitor was fed rectified pulses from the high-impedance B winding of the generator through a relatively high-resistance rectifier, it contributed materially to ripple reduction. As a class the filters operated with about 1 v of ripple across the input capacitor and 100 mv of ripple across the B voltage output at 1,500 c. This ripple frequency corresponded to a generator speed of 15,000 rpm, the minimum required for operation. At higher frequencies the ripple attenuation was proportionately greater.

The C bias potentials for thyratron and amplifier were developed across a resistor in the negative leg of the power supply filter. A single voltage of approximately −7.5 v was adequate for those fuzes having high-resistance grid circuits in their amplifiers. Here the full-bias voltage was applied to the thyratron grid and a high-resistance voltage divider contained in the amplifier supplied approximately −1.5 v to the amplifier grid. In fuzes T-51 and T-82 which used low-resistance amplifier grid circuits, separate resistors in the negative leg of the filter provided the two bias voltages.

Due to the steep load-regulation characteristics of the power supply an undesirable spread in output voltages would result from the normally encountered spread in the plate current demands of the tube complements. In production, bleeder resistors were selected to bring each power supply to very nearly a standard load condition. This is discussed in detail in Chapter 6.

The requirements upon the output filter capacitor for service in detonator firing and in delayed arming have been treated in Section 3.3.

3.4.8 Power Supply Circuits

Representative circuits for several power supplies are shown in Figures 75, 76, 77, 78, and 79. Values for the circuit components are included.

The basic power supply was the T-50 model of Figure 75. A typical T-50 assembly is pictured in Figure 26 of Chapter 6. The limits for acceptable operating characteristics are summarized in NDRC specification for power supply PS-1.[17]

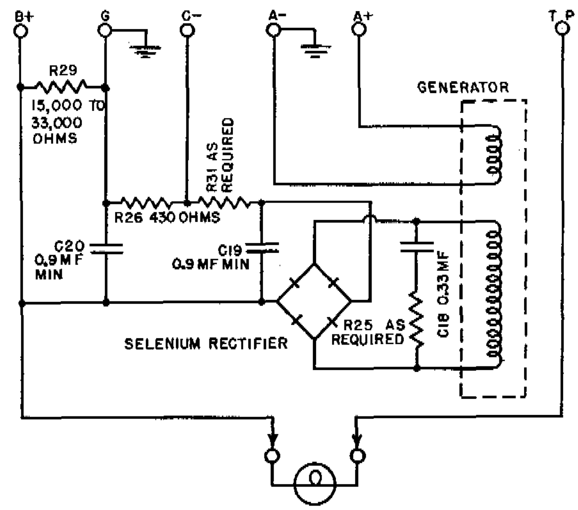

FIGURE 75. Schematic diagram of power supply of T-50 fuze.

The T-51 power supply of Figure 76 differed from the T-50 chiefly in respect to the C-bias circuit. Here a low-resistance source of amplifier bias was additionally provided.

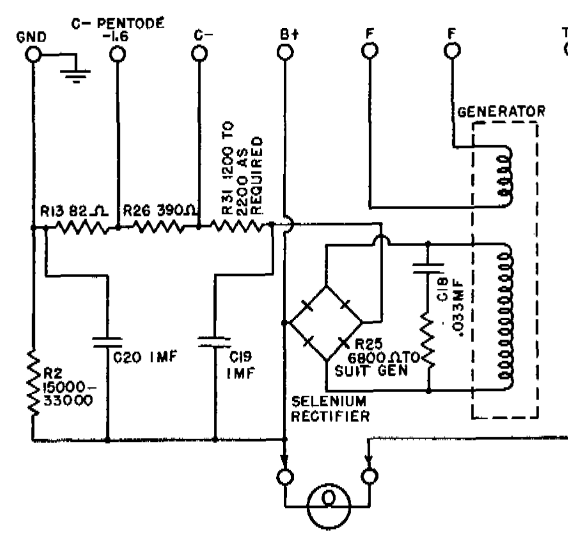

FIGURE 76. Schematic diagram of power supply of T-51 fuze.

The T-30 (T-2004) power supply is shown in Figure 77. This differed from the T-50 supply in that the detonator firing capacitor C20 was

charged through a resistor R27 to provide an electric arming delay.

The T-132 (T-171, T-172) power supply is shown in Figure 78. This used a bridge-type rectifier doubler. The doubled voltage was developed across capacitors C23 and C24, as shown. Voltage adjustment was effected by selection of series dropping resistor R35 and bleeder resistor R29. Electric arming delay was provided by the use of resistors R27 and R28 in connection with detonator firing capacitor C20.

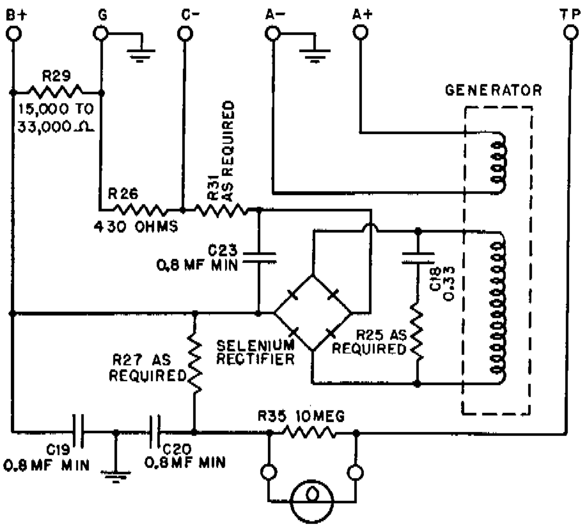

FIGURE 77. Schematic diagram of power supply of T-30 fuze.

The T-82 power supply is shown in Figure 79. This featured the use of compound regulation provided by C15, C17, and R19. A low-resistance bias supply for both thyratron and amplifier grids was provided by resistors R7 and R14.

3.5 COORDINATION OF ELECTRIC DESIGN[j]

3.5.1 The Coordination Problem

The design requirements for the various subassemblies of radio proximity fuze were determined on the basis of somewhat arbitrary decisions concerning expected performance for each part of the fuze. Coordination of these requirements involved many considerations which generally required compromise to make them mutually compatible. The one overall consideration was the military requirement for performance: the fuze must detonate a particular missile or group of missiles when the fuzed rounds were in a specified space region with respect to the target. Along with this prime requirement were generally a host of secondary requirements, such as (1) the fuze must occupy a predetermined position on the round and must fit a fuze well whose dimensions are fixed; (2) the space allotted to the electronic components was determined by mechanical considerations which govern shape and volume; (3) conditions of use which include temperature, humidity, high-altitude operation, and storage life; and (4) special electrical features

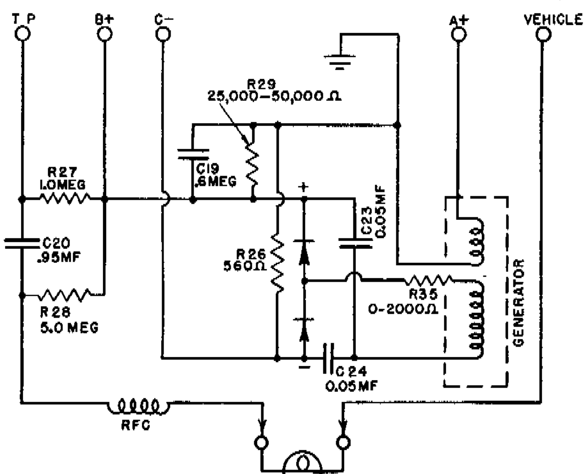

FIGURE 78. Schematic diagram of power supply of T-132 fuze. This is the same as that for fuzes T-171 and T-172.

relating to time of activation, circuit switching for arming or self-destruction, and simultaneous use of a quantity of fuzed rounds without mutual interference. Mechanical design is discussed in Chapter 4; it will be referred to here only with respect to the limitations which mechanical problems imposed on electric design.

A logical method of discussing design coordination is to separate the fuzes according to intended application (antiaircraft or ground approach) and also according to the type of missile on which they were to be used (bombs, rockets, or mortars). However, in the actual

[j] This section was prepared by the editor with the aid of W. S. Hinman, Jr., Chief Engineer of the Ordnance Development Division, National Bureau of Standards.

course of development during World War II, each fuze, regardless of its application, was built largely on experience and designs which accrued from previous work. The factors influencing design depended so much on the state of the art that for the following discussion a chronological order is preferable. The presentation will be simplified by confining the discussion to the major projects.

Since one of the objectives of this section is to tie together the preceding four sections of the chapter, frequent references to these sections and other chapters in the volume will be necessary. The reasons for concentrating on doppler-type radio fuzes have been discussed in Section 1.2, and those reasons will not be repeated here.

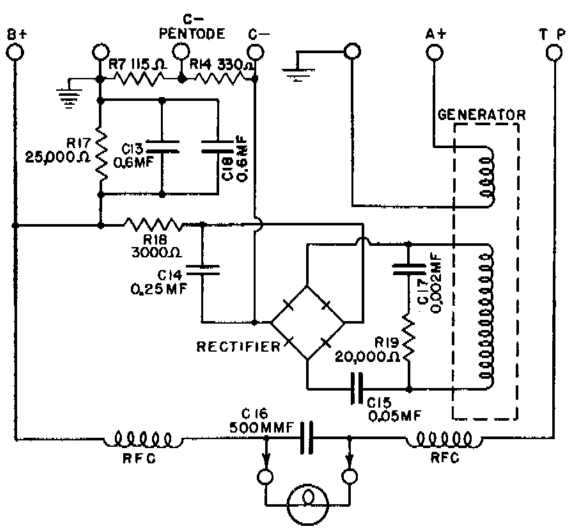

FIGURE 79. Schematic diagram of power supply of T-82 fuze.

3.5.2 Battery-Powered Rocket Fuze

The T-5 fuze for the M-8 rocket was developed for antiaircraft use. The requirement (see Section 1.1) was that the fuze detonate the rocket in the vicinity of an aircraft target and within the lethal range of the rocket's fragments. Although the rocket's fragmentation pattern was unknown, it was assumed on the basis of anticipated performance of the rocket that the region of greatest fragmentation density would be between 60 and 70 degrees off the forward axis of the rocket (see Section 1.3). It was next decided on the basis of knowledge of the radiation patterns of linear antennas and of experimental investigations (see Section 2.8) that by using the rocket as an antenna, proper directional sensitivity could be obtained.

Size and Location. Various methods of exciting the rocket as an antenna were investigated, but it was readily appreciated that the optimum location of the fuze from mechanical and service viewpoints was the nose of the rocket. Hence methods of exciting the rocket from the end were developed (see Section 2.7) which would give proper loading for the oscillator and the desired directional sensitivity. When it was established that a nose location for the fuze was compatible with electric design, dimensions for the fuze were worked out. Since the rocket was also under development at the same time, it was relatively easy to coordinate the fuze requirements with rocket design. However, space limitations were very important, since the larger the fuze, the less high explosive the rocket warhead would carry. Enough exploratory work on circuits had been done at Division 4's central laboratory at the National Bureau of Standards with hearing-aid type tubes to establish minimum space requirements for the working part of the fuze. Also, the National Carbon Company had developed a small dry battery in connection with Section T's shell fuze program which was suitable for use as a power supply. It was agreed that the T-5 fuze would occupy the following volume: (1) a cylinder $2\frac{3}{4}$ in. in diameter and $5\frac{1}{4}$ in. long, *interior* to the warhead, plus (2) a cone of the same diameter and $2\frac{1}{4}$ in. long *exterior* to the warhead and conforming to the contour of the ogive of the rocket. (See Figure 1 of Chapter 5.) It was essential that the fuze have some external volume in order to provide proper excitation of the rocket (cf. Section 2.7).

Choice of R-F Parameters. (1) *Carrier frequency.* The miniature triodes which had been developed (see Section 3.1.4) worked fairly well in simple oscillator circuits at various frequencies up to about 200 megacycles. It was

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desired to select a range of operating frequencies below this value at which the missile would be approximately resonant and also which would give the proper directional sensitivity (see Sections 2.7 and 2.9 for theoretical discussion and Figure 33 of Chapter 5 for radiation pattern on the M-8 rocket). A range of operating frequencies was desired in order to increase the difficulty of jamming. It was also realized that if a range of operating frequencies was allowed, the production problem might be simplified. (Actually, as is shown in Chapter 6, it was found practicable to build oscillators for fuzes with remarkably small spreads in carrier frequency.)

Accordingly, three design centers for carrier frequency were selected, and named, for security purposes, Red, Yellow, and Green (see Glossary). All of these were near enough to the resonant frequency of the missile to give suitable loading and also to give suitable directional sensitivity.

2. *Oscillator and detector.* One of the most direct methods of fulfilling the requirement (cf. Section 1.1) that the fuze be resistant to countermeasures is to radiate lots of power. Accordingly, as shown in Section 3.1.1, an oscillator circuit was selected which would give stable oscillation under full power. (The radiated power ranged from 100 to 200 mw.) A sharply tuned diode detector connected to the antenna-coupling circuit gave suitable indication of proximity to a target (Section 3.1.2). Since the fuze was intended for use on single missiles, the tuning of the detector introduced no serious problems.

Fly-over tests and pole tests (see Sections 2.11 and 2.12) provided basic data on the magnitude of signals which could be expected in the detector circuit due to approach to a target. In order to trigger a thyratron at distances of 50 to 100 ft from an aircraft target, it was evident that appreciable amplification of the signal was necessary.

Designation of Amplifier Requirements. The amplifier characteristics selected were such that a single amplifier design could be used with all three of the carrier frequencies selected.

The factors involved in designing the amplifier characteristic to assist in control of the burst surface have been discussed in Section 3.2. As shown there, the gain-frequency curve of the amplifier was also shaped to reject certain undesirable signals such as vacuum-tube microphonics. The requirements for overall gain were determined by the magnitude of the input signal and of the output required for reliable operation of the thyratron. As indicated in Section 3.3, the spread in critical bias voltage for thyratrons averaged about 0.4 v. To insure reliable operation, a firing signal of about ten times the average spread value was desired. Accordingly, a bias was selected so that a firing signal of approximately 4 v was required. Under these conditions, a single-stage amplifier was able to provide sufficient amplification to cause operation of the fuze at distances between 50 and 100 ft from an aircraft target.

Power Supply. The urgency of the request for an antiaircraft rocket fuze was such that there was no time to develop an ideal power supply. Accordingly the small dry battery developed by the National Carbon Company was adopted for the T-5 fuze, although its limitations with regard to low-temperature operation and shelf life (see Section 3.4.3) were fully appreciated. Coordination of vacuum tube and battery design yielded a 1.5-v A supply and 135-v B supply. The tubes and circuits were further designed so that satisfactory operation would continue as the A and B voltages dropped to values of about 1.1 and 100, respectively. This provision extended considerably the useful range of the batteries.

It was realized that the high internal impedance of the miniature B battery might make the firing of the detonator through the thyratron a marginal proposition so a detonator firing capacitor was added to the power supply (see Section 3.3.3). With this arrangement, firing of the detonator was certain as long as the B voltage did not drop below 100 v.

Since dry batteries deteriorate in storage, the fuze was designed to allow testing of the batteries (and also the fuze) prior to assembly in the field (see Section 7.7).

Arming. Initial requirements were to have the fuze arm about 0.4 sec after launching of the rocket. To allow stable operation of the fuze at arming, the tube filaments and circuit con-

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stants were chosen so that all warmup transients of firing magnitude were over in about 0.2 sec. To give the circuits maximum opportunity for warmup, the arming switch was arranged to close the filament circuits during setback of the rocket (see Section 4.3.1). Later the arming was delayed first to 0.7 sec and then to about 1 sec, but the rapid warmup features of the circuits were retained.

Mechanical Stability. Since a radio proximity fuze functions when a signal of requisite amplitude reaches the thyratron grid, it was important to prevent the generation of spurious signals which would result in malfunction of the fuze (see Sections 3.1.5 and 3.2.6). Although proper amplifier design noticeably reduced some spurious signals, it was more effective to develop tubes and circuits which would not generate spurious signals or respond to induced vibration. The results of this development have been covered in Sections 3.1 and 3.2.

The fuzes were subjected to intense vibration in flight due to air turbulence produced by the missile and also due to vibration of the fin structure of the missile. In very early experimental fuzes, efforts were made to shock-mount the fuze to prevent these vibrations from reaching the tubes. This procedure proved unsatisfactory, and in all final models the tubes and other components were firmly embedded in position as a solid part of a single fuze assembly. Embedding was accomplished with cements and potting compounds (see Section 4.7) which had the added advantage of preventing penetrating moisture from altering the electric characteristics of the circuit.

There remained the problem of spurious signals generated in the missile itself. Loose fins on the rocket could produce variable electric contacts and consequently variations in the impedance of the rocket antenna, which would trigger the fuze (see Section 9.2.2). Afterburning of the rocket powder produced trails of ionized gas behind the rocket, which trigger the fuze (Section 9.2.2 and also 2.13). Reduction of these difficulties was accomplished by redesign of the rocket in cooperation with representatives of the Ordnance Department and Division 3, NDRC.

Coordination of Development Groups. Numerous laboratories worked on various phases of the T-5 development for Division 4. Their efforts were coordinated in the division office with the assistance of the division's central laboratory at the National Bureau of Standards. In designing the fuze for production, one manufacturer handled the container for the fuze, one the arming switch, one the battery, and five worked on the electronic unit. Since each of the latter had facilities which were best adapted to certain types of construction, the need for immediate production overbalanced the desire for production uniformity, and some three different structural designs were worked out. Each company was allowed to use that design which was best suited to its facilities. However, all companies were required to hold to the same performance specifications and to hold essentially the same overall dimensions. The difference of design did not result in any material difference in field performance; the production of all manufacturers gave a relatively high level of performance in proof tests (see Section 9.2.3).

3.5.3 Generator-Powered Bomb Fuzes Ring Type

A request for an air-to-air bomb fuze was made near the end of the T-5 program. This application meant that a longitudinal antenna was essential (cf. Sections 1.3 and 2.8). Progress on the development of a wind-driven generator had advanced to the stage where it appeared practicable to use it for the power supply. It appeared expedient to use the same type of circuits and general layout which had proven practicable on the T-5 project.

An essential difference between the requirement for the bomb fuzes and the T-5 fuze was that bomb fuzes were to be used on a variety of missiles of sizes from 100 to 10,000 lb.

After development was fairly well advanced, the requirement was changed to an air-to-ground application. In order to take advantage of the work which had already been done, it was demonstrated that the amplifier alone could be redesigned to give acceptable air-to-ground performance. As a parallel but lower-priority

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project, work was started on a transverse antenna (bar-type) fuze (Section 3.5.4). The following discussion refers only to the air-to-ground application.

Size and Location. The bomb fuzes were intended for use on existing missiles so the fuze was dimensioned to fit into standard fuze wells. Since most bombs were designed to carry nose and tail fuzes, there was a choice as to location for the proximity fuze. As shown in Figures 21 to 24, Chapter 2, the radio sensitivity with an end-fed antenna is greatest away from the exciting end. Therefore, a tail location for the fuze would give greater sensitivity. However, proximity of the fuze and its antenna to the fin structure, which was known to vibrate intensively during flight, led to the conviction that such a location would produce malfunctioning of the fuze.

Another consideration was that of the length of the fuze beyond the bomb. The fuze antenna must be spaced and insulated external to the missile in order to properly excite it as an antenna (see Section 2.7). Because of the possible shielding effect of the fins (see diagrams in Figure 16, Chapter 2), a greater extension was required for a tail fuze than for a nose fuze. Furthermore, the required extension would make the overall length of a tail fuze (since it would be anchored to the bomb in the rear fuze well) several times greater than a nose fuze. The great length would make it much more susceptible to vibration.

These considerations led to selection of the nose location for the most intensive development. Nose-mounted bomb fuzes with longitudinal antennas were generally referred to as T-50 type or ring type (see Figure 5, Chapter 1).

Dimensions of the nose-mounted fuze external to the fuze well were fixed as follows. A survey of clearances in the bomb bays of various bomber aircraft led to the conclusion that extensions of more than 5 in. beyond the nose of the bomb would lead to difficulties in stowing fuzed bombs. Accordingly, the length of the fuze external to the bomb was required to be less than 5 in. The external radial dimension was relatively unimportant. However, a diameter of 3½ in. (approximately) was found adequate to hold the fuze and was adopted as standard.

Ballistic tests showed that the size and shape adopted for the fuze did not appreciably change a bomb's flight. Thus, the VT-fuzed bombs could be used with standard bombing tables.

Some work on lower priority was done on tail fuzes. There was a requirement for air-burst fuzes for large blast bombs (4,000- and 10,000-lb). For this application there was difficulty in exciting the missile with a nose fuze and it was planned to build a special antenna system, as part of the fuze, in the large tail structure. Considerable work was done, but the project (fuzes T-40 and T-43)[199] was curtailed on the basis of incomplete reports that there was no advantage in air-bursting blast bombs (see Section 9.4.5). When the advantages of air-burst blast bombs were finally established, the T-51 fuze development was well enough advanced for considered use on the big bombs.

Another tail fuze project was for a 90-lb fragmentation bomb. In this application it was planned to use a special nonconducting fin on the bomb. Details of the work which was still in progress at the end of World War II are given in reference 196 of Chapter 2. One major advantage of a tail-mounted fuze on an air-burst fragmentation bomb is the increased lethality of the weapon. In most bombs, the greatest density of fragments is away from the point of detonation (cf. Figure 1B, Chapter 1) and nose initiation of the explosion is therefore desirable for air-burst bombs. Various schemes were tried for obtaining tail initiation for bombs when used with the nose-mounted proximity fuzes.

Choice of R-F Parameters. (1) *Carrier frequency.* The requirement that the fuze operate on more than one bomb presented a problem in the selection of an oscillator frequency. As has been shown in Chapter 2, both the directivity pattern and the radiation resistance change appreciably with bomb size. There was no singly practicable frequency (at the time) which would be satisfactory on all the bombs. A very low frequency (wavelength long compared to the bomb's length) would give reasonably uniform performance on a variety of bombs, but the radiation resistance would be

intolerably high. Circuit techniques and r-f insulating materials available at the time led to the conclusion that radiation resistances in excess of 30,000 ohms would be impracticable, due to loss in sensitivity.

The compromise solution was the selection of two frequencies, one for the 500- and 1,000-lb bombs and one for 100- and 260-lb fragmentation bombs and the 2,000-lb bombs. The fact that the latter bomb was about twice the length of the 100- and 260-lb bombs made a single frequency for those bombs practicable. (See Figure 16 of Chapter 2 for drawings of bombs.) The frequencies selected were designated as White (see Glossary in Appendix 1) for the first application above and Brown for the second. The first production models of the fuzes were designated as T-50-E4 and T-50-E1, respectively. Although the details of the argument leading to the selection of these frequencies are too lengthy to give here (see reference 8 of Chapter 2) the basic data on which the argument was based are included in figures in Sections 2.7 and 2.8.

Toward the end of World War II, circuit development had advanced to the stage where adequate r-f sensitivity could be obtained at higher radiation resistances.[118] It was then shown that a single frequency designated as "Brown minus 20" would be practicable for the bomb sizes 100- to 2,000-lb, inclusive.[140]

2. *Choice of circuit.* The oscillator-diode circuit used in the T-5 fuzes was selected for use in the first T-50 fuzes. Tuning of the diode circuit presented some problem, since each fuze was intended for use on more than one missile and tuning could be optimum on only one. The methods of resolving the tuning compromise are discussed in reference 31 of Chapter 2 and the selected procedures for tuning are listed in Section 7.2.

3. *Antenna design.* The evolution of the antenna cap for T-50 type fuzes is discussed in Chapter 4 from the mechanical point of view. Electrically it was desired to have a large cap to reduce radiation resistance (see Section 2.7). The forward extension of the antenna was limited by overall length consideration and the rearward extension by undesirable shunting capacitance on the radiating load. Another factor was the presence of the rotating windmill; it was desirable that it be located in a near-zero radio field. Compromises between the various factors led to a ring shape for the antenna of about 1-in. length and big enough in diameter to enclose the windmill (see Figures 16 and 18 of Chapter 4). The latter figure shows the antenna in an earlier and less satisfactory form.

Amplifier Requirements. As shown in detail in Section 3.3, the gain-frequency characteristic of the amplifier was adjusted to compensate for the variations in r-f sensitivity for various terminal ballistic conditions. Here, too, a compromise characteristic was required because of different r-f properties of the missiles.

The use of a generator power supply introduced additional requirements on the amplifier:

1. A very sharp reduction in gain above the pass band was necessary in order to reduce the response to hum and ripple from the generator. In addition, hum injection circuits were employed to reduce the net effect of hum at the thyratron grid. These were incorporated in the feedback network of the amplifier.

2. The generator power supply made it possible to obtain fuze operation at very low temperatures (−40 degrees) as was desired by the Services. Accordingly, the components of the amplifier had to be selected with due regard to their temperature coefficients in order that the amplifier would perform properly over a wide range of temperatures.

3. Although voltage regulation circuits were employed as part of the power supply, they were not perfect and variation in supply voltage was inevitable. Thus, the amplifier design had to be arranged so that the essential gain characteristics would persist over a range of supply-voltage variations.

4. An average effective holding bias of about 4 v was selected for the thyratron as for the T-5 fuze. However, considerations leading to this selection were appreciably different in the case of generator-powered fuzes. The variable contributions of hum and microphonics produced a range of effective critical voltages (defined in Section 3.3), of about 1 v. This was appreciably larger than the range of critical biases for the T-5 fuze. Also, the method for

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obtaining C biasing voltages yielded a spread of bias values of about 1 v. Thus the average effective holding bias was only about twice the range of variations. Although a larger margin might have been desirable, the requirements for sensitivity were such that the margin was made as small as was compatible with good field performance.

Power Supply. The various design considerations leading to the development of a wind-driven generator for the power supply have been adequately covered in Section 3.4.5. Factors relating to certain compromises in design are as follows:

1. *A supply.* The supply for the tube filaments was raw alternating current at 1.4 v. Rectifiers or commutators to supply direct current would have been unduly complicated and it was simpler to design the circuit to operate with alternating current on the filaments.

2. *B supply.* Plate power was rectified and filtered and supplied at about 140-v average value. Rectification and filtering were essential for the proper operation of the types of circuits employed. Some saving in space was effected by using the detonator firing capacitor also as a filter capacitor.

The rectifier was the critical element in the power supply as regards low-temperature operation of the fuze. Although it performed satisfactorily down to −40 C, requirements for still lower temperature would necessitate redesign of the rectifier. Some special circuits were investigated for operation on raw alternating current, but none gave completely satisfactory performance.

3. *C supply.* Circuits were designed to obtain grid-bias voltage from the B supply rather than require a separate output from the generator. One advantage of this arrangement was in self-compensation. Overall sensitivity tended to remain constant as the B-supply voltage varied.

4. *Electric frequency.* It was imperative that the frequencies delivered by the power supply be outside the amplifier pass band. Accordingly, the number of poles in the generator and its range of operating speeds were selected to give a minimum frequency of about 750 c under operation conditions.

5. *Regulation.* To compensate for the fact that the wind-driven turbine for the generator must operate over a wide range of missile speeds (about 300 to 1,000 fps), regulation of the output was essential in order that circuit characteristics remain essentially constant. Regulation circuits developed (see Section 3.4.5) kept the A and B voltages constant over the operating speed range within about ±5 per cent. Also, total voltage changes over the temperature range −40 to +60 C were less than 10 per cent. These changes were compatible with good performance of the oscillator and amplifier.

6. *Mechanical stability.* Perhaps the most serious problem introduced by the generator power supply was that of vibration caused by slight unbalance in the rotating system. This vibration tended to produce microphonics, particularly in the triode. Solutions were sought in two directions; nonmicrophonic tubes and circuits, and better balanced rotating systems. The work done on the two aspects of the problem is covered in Section 3.1.4 and in Chapter 4, respectively. No hard and fast rules or division of responsibility could be set for the two problems; they had to go hand in hand. The tubes had to be good enough microphonically to operate reliably under vibration from the generator, and the rotating system had to be sufficiently well balanced that it would not produce microphonics in the tubes. There was some indication that as balancing techniques improved, the generator vibration became small or negligible compared to that produced by the bomb in flight.

The vibration problem resulted in one general design criterion, namely, the rotational frequency of the generator should be outside the amplifier pass band. This was a more serious limitation on the selected range of operating speeds than the one mentioned above concerning the electric frequency of the generator output. (Electric frequency was usually three times rotational frequency.) An upper limit on rotational speeds was set by the durability of the bearings and the centrifugal strength of the Alnico rotors. In some later fuze designs, notably T-51, rotational frequency was on the upper edge of the amplifier pass band at arming.

Arming. The arming problems in generator-powered fuzes were largely mechanical and are discussed in Chapter 4. The requirements for warmup were less critical than those solved for T-5 fuzes. In some designs there was indication that firing pulses would be produced at arming, i.e., when the electric detonator was connected to the circuit. Either proper circuit layout, by-passing or choking, was adequate to eliminate this difficulty.

In rocket and mortar fuze applications, added RC arming was used. As shown in Section 3.3.6, there was an inherent spread in arming times by this method unless considerable care was taken in selecting component values.

Overall Stability. The same standards for rigid assembly used in T-5 fuses were extended and carried into the design of generator-powered fuzes. The problems were, of course, more difficult because of the high rotational speed of the power supply system. The special layout chosen for the fuze was probably the most difficult from a stability standpoint, but it had other advantages, as follows:

1. Circuit arrangements, previously developed, were used directly with only a minor modification to allow the generator drive shaft to pass down through the axis. However, it proved desirable to shield the drive shaft when it passed through the amplifier and oscillator block.

2. With the windmill on the nose of the fuze, the aerodynamic problems were simplified. Later models located the entire power supply in the front end of the fuze, dispensing with the long, high-speed drive shaft (T-132); others located the generator and turbine at the base of the fuze using a central air duct for directing air to the turbine (T-82, T-172). The latter arrangement introduced difficulties in circuit layout and space requirements due to the central air duct.

Difficulties experienced with T-5 and the extra vibration with the new power supply led to the elimination of all plug-in connections on T-50 type fuzes. The electric connections between the various subassemblies were soldered, and during the various laboratory tests, soldered connecting leads were used. Although this increased the labor involved in making tests, it insured that vibrating electric contacts within the fuze would not introduce spurious signals.

Spurious noise signals from the missile were another matter for consideration. Special washers were used to insure both good electric and mechanically stable contact between the fuze and bomb (see Chapter 4). Service instructions advised that both the fuze and fin be firmly secured to the bomb. Reasonably careful wrench-tightening usually proved adequate for good fuze performance. However, late in World War II a new washer was produced which gave excellent results with just hand-tightening of the fuze (see Section 9.4.3). Occasional difficulty was encountered with bomb fins (particularly T-92 on M-64 bombs) which could be eliminated only by unusual precautions (see Section 9.4.3). In such cases, alternative fuze designs were sought (see Section 1.5) since redesign of the bomb's fin structure was believed impracticable.

Coordination of Development Group. In general, the arrangements for coordinating development and experimental production followed the same procedure as for the T-5. Standardization was insisted on only when necessary, and considerable individuality was allowed in design detail in order to make maximum use of available facilities. Various types of oscillator, amplifier, and generator construction are described in Chapter 6.

3.5.4 Generator-Powered Bomb Fuze, Bar Type (T-51)

The T-51 bar type bomb fuze was developed specifically for air-to-ground application. A transversely excited antenna was part of the fuze and led to the name bar type. An underlying design consideration was to make maximum possible use of T-50 mechanical parts in order to expedite both development and production problems. Accordingly, the T-51 fuze was mechanically identical to T-50 fuzes except that a nose piece with transverse bars attached replaced the ring-carrying nose piece.

Size and Shape of Antenna. The overall length of the antenna was limited by the dimensions of the smallest bomb on which the fuze

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was to be used. A maximum 10-in. tip-to-tip length was imposed. (This was approximately the diagonal width of the fins for M-30 and M-81 bombs.) As long a length as possible (up to one-half wavelength) was desired in order to reduce radiation resistance and increase sensitivity.

Early experimental models of transversely excited fuzes had used screw-in dipoles, but considerable difficulty was encountered with vibration and variable electric contact. Accordingly, it was decided that greatest stability would be obtained with dipoles molded firmly into the nose piece. High-strength and low-loss dielectrics were desired and details of this investigation are given in Section 4.7.

Preliminary calculation indicated that the only suitable cross section for the antenna with adequate rigidity would be an airfoil section. Cylindrical cross sections would have given increased drag. The design chosen gave negligible drag in tests on 250-lb bombs. The dimensions of the section were selected as a compromise between rigidity and shunting capacity on the radiating load.

Electric Parameters. The first guess in choosing an oscillator frequency for T-51 fuzes was that the higher the frequency up to a value corresponding to a wavelength equal to twice the antenna length (suitable tube characteristics assumed), the better would be the performance. Actually, it turned out, owing to unavoidable electric unbalance of the antenna, that at higher frequencies the bombs became strongly resonant, and longitudinal excitation masked the transverse excitation. Consequently, an upper frequency limit was set at which bomb resonance would not be troublesome. A lower frequency limit was set by the allowable radiation resistance, below which circuit losses were intolerable. Designs centered around Yellow (see Glossary in Appendix 1) but a fairly wide range (10 megacycles or so) was permissible.

Oscillating-detector circuits (RGD) were developed to give good sensitivity under stable oscillating conditions (see Section 3.1). No tuning of the circuit was necessary and the fuze was usable on a wide variety of missile sizes (see Section 9.4.4).

The factors leading to the selection of amplifier characteristics are adequately treated in Section 3.2.

3.5.5 Generator-Powered Trench-Mortar Shell Fuzes

The last Service requirement for VT fuzes was for the 81-mm trench mortar for ground-to-ground use. This project required a major redesign of the fuze, since the effect of the fuze on ballistics of the round was one of paramount importance. Some of the mortar rounds weigh about 8 lb, and the addition of a 2-lb fuze would reduce the round velocity in about the ratio of the increased weight. A fuze such as those used on bombs and rockets would completely overbalance the round, and even if it were satisfactory from a range standpoint, the round would be unstable in flight. It was therefore necessary to reduce the volume of the fuze by a factor of about 3. An additional requirement was introduced by the necessity of withstanding accelerations up to 10,000g, which was about 100 times greater than that which rocket fuzes were required to withstand. Fortunately, the requirements for reduced size and increased ruggedness were compatible. Two types of fuzes were engineered for production because of lack of time to work out compromises and an optimum single design. One of these used a 2½-in. transverse loop antenna (T-172) and the other used the missile for an antenna. Both used essentially the same fuze circuits, the difference being similar to that between the transversely excited and the longitudinally excited bomb fuzes.

These fuzes were the first which were engineered without much structural design relationship to previous fuzes. They did, however, use the same type of components, there being only a minor modification of the generator and the rectifier assembly (see Chapter 4). There was, however, considerable crowding together and the clear-cut shielded separations between radio frequency, audio frequency, and power supply, adhered to closely in previous designs, were not followed. In the longitudinally excited fuzes, the antenna cap was appreciably elongated to decrease the radiation resistance, already high because of the short missile. In

order that the space would not be wasted, the electric assembly, including power supply, was located within the antenna (see Figure 42, of Chapter 4).

The longitudinal fuzes were built to two designs which were externally similar but which use radically different internal construction. One of these (T-132) represented the first application of a printed circuit technique (see Chapter 6) in which resistors and their connecting wires were printed directly on ceramic plates with appropriate points of plating for the attachment of tubes, small ceramic and paper condensers, and for the connection to the power supply and detonator. The aim of this printed circuit development was threefold: (1) reduction in size through the elimination of the bulk of individual components such as commercial resistors, (2) increase in production speed, and (3) reduction of cost. This fuze was nearest to production status (of the mortar fuzes) at the close of World War II.

The second version of the longitudinally excited fuze (T-171) utilized essentially the same circuit system but different types of components. It was felt that the printed circuit technique was something of a gamble, since it represented not only a development of the technique but of the fuze as well. For this reason, it was deemed necessary to engineer a similar fuze but using standard components whose performance was well established. Further details of the mortar shell fuzes, on which some design compromises were still in progress at the end of World War II, are given in Sections 3.1, 3.2, and Chapters 4 and 5.

Chapter 4

MECHANICAL DESIGN[a]

4.1 GENERAL REQUIREMENTS

4.1.1 Introduction

In discussing the various aspects of the mechanical design and construction of proximity fuzes, two approaches are possible. One is to treat the problems from an abstract point of view and to show how the final solutions followed inevitably the theoretical considerations involved. The second approach is to give the history of the mechanical development of the fuzes described in this report and to show how each fuze was the successor to its predecessors and how the considerations of expediency determined its details.

It has been mentioned in the introductory chapter that time and the availability of materials and tools were a controlling factor in most of the engineering designs. This was particularly important in the mechanical design of proximity fuzes and consequently the history of the development is intimately related to all the mechanical designs. It would have been very pleasant for the designers if, at the beginning of the development of each fuze, they were given carte blanche in respect to the design of the fuze, its components, the vehicle, and even some control as to the method of its launching. Unfortunately, this was not the case, particularly in the latter part of World War II, when the specifications of suitable projectiles and the methods of their launching preceded the development of the proximity fuzes.

The limitations on the availability of components and on the interchangeability of the proximity fuzes with other types made all other design considerations secondary. The primary consideration was always time. It is for these reasons that, after some discussion of the general mechanical requirements of proximity fuzes, the detailed treatment of each fuze will be taken in its chronological order so that the reasons for the details of its construction will be more readily understood.

[a] This chapter, except for Section 4.7 was written by Jacob Rabinow of the Ordnance Development Division of the National Bureau of Standards. Section 4.7 was written by Philip J. Franklin of the same organization.

4.1.2 Arrangement of Main Components

Let us consider first the case of the longitudinally excited radio proximity fuze. Since the vehicle itself is part of the antenna system, it is highly desirable for the antenna insulator to be as near to the mid-point of the total round as possible. By the use of special projectiles such a condition could be closely approximated. Very early in the program both rockets and bombs of special construction were built and tested; but it soon became apparent that it would be far more desirable to build fuzes which would fit standard missiles, and the development of all future fuzes was conditioned by this decision.

All of the radio fuzes which went into production during World War II were of the one-piece type that fitted into the fuze well at the nose of the projectile. As a result of this, the forward antenna in all cases was a small fraction of the total length of the vehicle. In the case of the transverse antenna fuze there were other limitations on the antenna size. Mainly, the combined length of the dipoles should not be over 10 in., which was less than the maximum diameter of the M-57 250-lb bomb and only slightly greater than the diameter of the M-30 100-lb and M-81 260-lb bomb, and the effects of the dipoles on the fall of the bombs should not require modification of the bombing tables.

The placement of the photoelectric fuze in the nose of the vehicle presented a very happy solution, since this position was the most natural for obtaining the "forward looking" sensitivity pattern desired. In all the proximity fuzes, with the exception of the T-132 and the T-2005 which will be treated later, the general arrangement was as follows: The antenna and oscillator unit, or the photocell, were at the forward end of the assembly, followed immedi-

ately by the audio amplifier. The power supply, consisting either of a battery or the generator with its associated rectifier and filter, was mounted below the electronic assembly and was, in turn, followed by the arming system and the explosive train.

4.1.3 Rigidity

A prime qualitative mechanical requirement in the design of the fuzes was the production of an assembly as rigid and as quiet as possible. Since the proximity fuzes are, in general, extremely sensitive (one is tempted to say delicate) devices, the problem of microphonic noise is perhaps the most difficult one of all to solve. When it is remembered that these fuzes move through the air at speeds up to 2,500 fps and contain turbines and generators rotating at speeds reaching 2,000 rps, a much clearer picture can be had of the difficulties involved.

Dynamic balancing of the high-speed rotating elements was utilized with great success. Special balancing equipment, which could be easily and cheaply manufactured was developed as incidental to the fuze program.

4.1.4 Size

The second major requirement in the design of the fuzes concerned the limitations on size. The fuzes were to be, as far as possible, interchangeable with existing mechanical fuzes and were to be adaptable to the projectile with minimum effect on its ballistic properties. In the case of the larger bombs, this was not particularly difficult, since the effect of the fuze on the flight of the bomb is relatively small. However, the attempt to match the ballistics of the impact fuze with a radio fuze for the 81-mm mortar shell was not accomplished successfully during World War II. The fuzes that were built were appreciably larger than the impact fuzes and resulted in the decrease in range of approximately 25 per cent.

4.1.5 Other Requirements

There were many other more or less secondary requirements, such as complete safety in handling, long shelf life, ruggedness in shipment and handling, ability to withstand heat, cold, and the humidity of the tropics, and the adaptability to as many projectiles as possible. There were special requirements for simple changes of fuze characteristics in the field, such as changes in the arming time, the optional inclusion of *self-destruction* [SD] of the adaptation of the fuze to air-to-ground or to air-to-air service. How the particular mechanical requirements were met will be described separately for each fuze.

4.2 SAFETY AND ARMING

4.2.1 Comparison with Other Fuzes

A special note should be placed here about the general safety and arming requirements of the proximity fuzes. With the possible exception of a time fuze, the proximity fuzes present the most difficult problems as far as safety and the arming characteristics are concerned. It is quite obvious that the very nature of a proximity fuze is such that when fully armed and energized it presents extreme hazard to anything in its immediate vicinity. Accordingly, great effort was spent in keeping the various fuzes inactive until safely away from their point of launching. It is well to point out here that one of the great advantages of the generator as compared with the battery is its greater safety. A generator-powered fuze equipped with only an electric detonator is a very safe device when the turbine is not turning at a high speed.

Very early in the work the Ordnance Department specified that all proximity fuzes be equipped with powder train interrupters so that, if the switching and electric safeties failed in some manner and resulted in an explosion of the electric detonator, the main explosive would remain unaffected. This is also the principle followed in most of the American mechanical fuzes. The only notable exceptions to this rule are the American bomb tail fuzes, in which the detonators are generally in line with the main explosive, but the striking pin is located away from the primer until properly armed by a very

rugged and simple mechanism. This emphasis on powder train safety is not seen in fuzes of other nations, particularly those of Germany. Both the mechanical and electric fuzes as used by the Germans almost invariably had the explosive elements in line and relied for safety on electric or mechanical devices ahead of the explosives.

The main objection to an in-line detonator is the possibility of its going off either because of a violent mechanical shock or because of the heat resulting from fire. The advantage of such an arrangement is the obvious simplicity and compactness.

4.2.2 Difference between Rotating and Nonrotating Projectiles

In general, the design of a safety mechanism for a fuze should use the cardinal principle that a fuze must arm only when subjected to all the forces it experiences when released against the enemy. The more varied the nature of these experiences, the simpler is the problem of making the fuze safe for our own troops. As an example, a fuze which is fired from a rifled gun experiences linear and rotational accelerations of great magnitude, large centrifugal forces on all components, and the effects of high velocity of travel through air; however, a bomb dropped from a plane experiences very little linear acceleration, practically no rotational acceleration, and experiences the impact of a much slower airstream. The rockets and the mortars are somewhere between the bomb and the rotating shell. Some of the rockets revolve, others do not. Some are accelerated at approximately $10g$, others at several hundred g. The trench mortar shell experiences accelerations up to $6{,}000g$ with no rotation. Beside taking advantage of all these "natural" conditions present in firing of the various projectiles, other arming means may be employed.

4.2.3 Possible Methods of Arming

Manual Arming

Manual arming is perhaps the most common. It generally consists of manually setting the arming mechanism to operate after launching or actually completely arming the fuze. There are many obvious objections to this approach, and it was given up early in the program of this division and was not employed in any of the fuzes which actually reached the production stage. Partial manual arming, such as removal of the safety pin in the trench-mortar fuze, was built into the T-132, but the later developments at the conclusion of World War II made even this manual operation unnecessary.

It is interesting to note that in the first of the proximity fuzes designed by the British at the beginning of World War II, the powder train interrupter was manually armed; that is, the interrupter slider was moved into position by means of a screw driver. If the round were not fired, someone had to remember to move the interrupter out of line.

Use of Arming Wire

In the case of our bomb fuzes we used the traditional method of releasing the windmill or the turbine by means of an arming wire that was attached to the plane. While this method of arming is open to very serious objections and was the only one that resulted in some accidents, the considerations of standardization of the plane equipment were such that no changes in this procedure could be made during World War II. It is possible theoretically to arm a bomb fuze automatically by making use of the fact that a fin-stabilized projectile in flight experiences a deceleration only in the direction of its longitudinal axis; in practice this is difficult because of the low value of this acceleration and because it is conceivable that a plane may move in a path and at velocities equivalent to those of a freely falling bomb.

Air-Travel Devices

To insure the arming of the bomb fuzes at a safe distance from the launching plane, air-travel devices were connected to the windmills (or turbines) so that a required number of windmill turns had to elapse before the fuze would be armed. Although this is very simple in principle, certain difficulties arose in practice. Different operational conditions required different distances to arming. Dive bombing

techniques required quick arming, while formation flying required very large arming distances. This difficulty was recognized early in the work, but the pressure of time was such that variable arming was not introduced into the fuzes, and supplementary devices were employed for this purpose.

One of these devices was the T-2 arming delay shown in Figure 1A. This device was fastened to the bomb fuze and was set to come off after any desired length of air travel from 0 to 20,000 ft.[10] The regular arming mechanism of the fuze remained inoperative through this part of the cycle and operated in its normal manner only after the T-2 device was thrown off. (See Figure 1B.) A cover using a similar mechanism was also developed for the T-50 series of fuzes and is shown in Figure 2.

EFFECT OF AIR PRESSURE

The effect of air pressure on the nose of the projectile was also considered as a possible source of energy for arming rocket fuzes. One such system was built and tested (see Figure 3), but was abandoned in favor of "setback" devices.

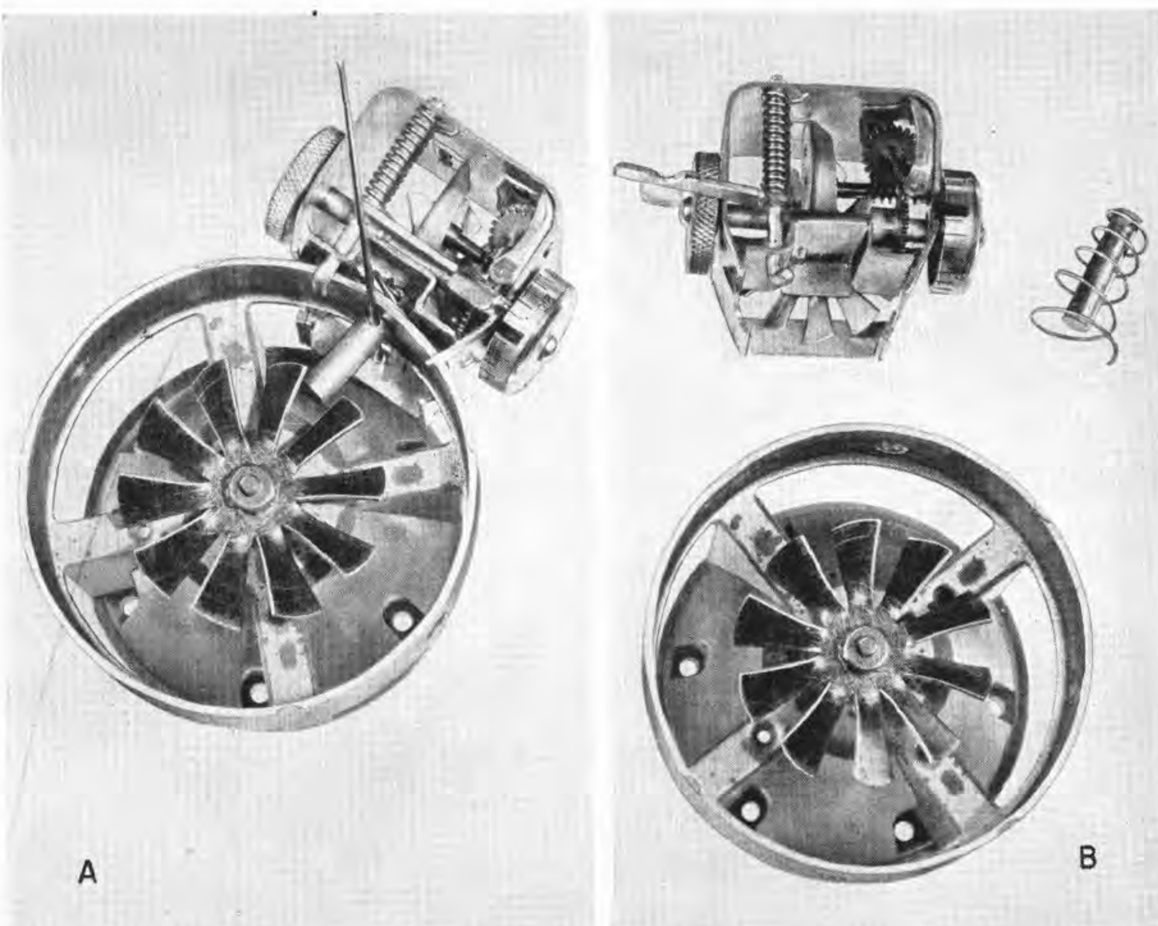


FIGURE 1. A, T-2 arming device in place. This delay installed on antenna ring prevents rotation of vanes. Dial on delay may be set in increments of air travel up to 20,000 ft. B, T-2 delay after operation. When arming delay operates, it is detached from ring, allowing spring-loader plunger in ring to fly out, thus unlocking vanes.

CLOCKS AND TIMING DEVICES

The use of clocks and timing devices in general was given very serious consideration, espe-

cially since most of the ballistic tables used by the Air Forces in the dropping of bombs are not given in terms of air travel. Nevertheless, clocks were not used in any of the fuzes developed up to the end of World War II because of the serious objection to their lack of safety. A clock driven by a prewound spring is inherently a dangerous device, since once started it goes to the completion of its arming cycle. Near the end of World War II the thinking in connection with the clocks underwent a change and, as will be mentioned later, the trench-mortar fuze was being redesigned to use a 10-sec mechanical delay in its arming mechanism. Also, several schemes were suggested in which the clocks would be driven by an air turbine so that they would not be capable of operation unless the fuze were subjected to an airstream of high velocity.

In the case of the rocket and mortar fuzes, main reliance for safety was placed on the use of setback or inertia-operated devices that were developed to a high degree of perfection. This resulted in fuzes that were extremely safe in handling; in fact, of all the thousands of fuzes built, tested, and used, there was not a single malfunction due to the failure of such a safety mechanism.

Acceleration Integrators

A new principle of setback or inertia arming was evolved in Division 4's central laboratory at the National Bureau of Standards. It consists, in essence, of the incorporation of some form of an acceleration integrator into the fuze arming mechanism. This mechanism can be so designed as to preclude the possibility of the fuze's arming, unless it attains a desired velocity. This is a sharp departure from the previous practice of using setback devices that could be triggered by intense shocks of short duration such, for instance, as are experienced by a shell in landing on a hard surface when accidentally dropped from some considerable height. In rotating shells this problem has never been serious because centrifugal force can be used in conjunction with the setback devices in order to make the latter shockproof. For mechanical fuzes for the nonrotating shells of the mortars, the setback device is made safe against accidental shocks by the use of a manually removable arming wire. Also, the large values of accelerations experienced by these shells make it relatively easy to design a fairly

FIGURE 2. Alternative arming delay. This delay completely encloses nose of fuze, preventing air stream from reaching vanes. When it operates, it opens and flies off fuze as shown in picture at right.

safe mechanism even if the arming wire were not used.

When work on rockets and fuzes for rockets

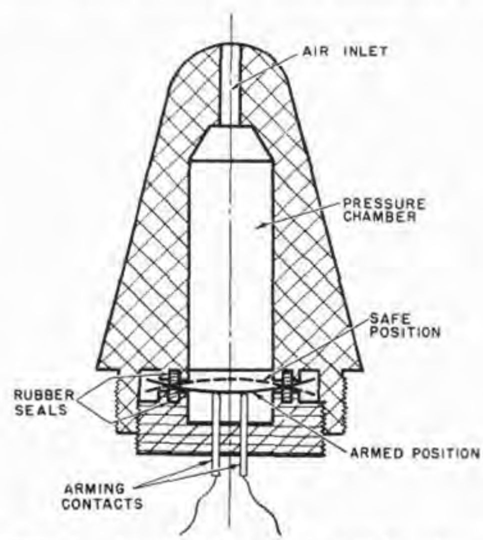


FIGURE 3. Arming device actuated by air pressure.

was begun, however, it became apparent that setback devices which operate at values of 10 to 200g were extremely sensitive to accidental

shock. The British in one of their early setback-operated switches employed a spring retained weight that drove a flywheel through a series of step-up gears (see Figure 4). While this type of device does act as a type of acceleration integrator, it presents a real danger when subjected to a very large acceleration of short duration. Once the flywheel is started, it tends to drive the mechanism to completion, even though the acceleration ceases.

The other type, a weight retained by a spring, acts as an escapement meshing with a flutter bar. When subjected to an accelerating force greater than the force of the spring, the weight moves toward the tail of the projectile in a series of short steps. The overall cycle, therefore, requires an appreciable time; if the acceleration is of very short duration, either because of an accidental shock or incorrect burning of the propellant, the weight does not reach its extreme rear position but stops and is moved

FIGURE 4. Acceleration-operated arming device. This is a British design developed for use on their rocket fuzes.

To overcome these objections a series of arming mechanisms was devised which can be divided into two basic types. One is a mechanism containing a weight retained in its forward position in the projectile by a spring which determines the minimum value of acceleration necessary to operate the mechanism. The weight is connected to a toothed wheel, which back to the initial starting position by the spring. A typical mechanism of this type is illustrated in Figure 5, showing the arming mechanism of the T-4,[b] T-5, and T-6 fuzes. The same escapement which is used to retard the weight during its initial arming cycle is also

[b] The T-4 photoelectric fuze is described in Division 4, Volume 3, Summary Technical Report.

employed later to delay the final arming of the fuze. This will be discussed in detail under a separate heading.

The second general class of shockproof arming mechanisms employed the action of separate inertia elements, each of which is retained by its own spring. Consider Figure 6, which illustrates the following: A weight A which is free to move for 1 in. is retained in its forward position by a 100-g spring. Mounted in close proximity to this weight is another similar weight B with a similar 100-g spring. It can also move 1 in. but only after the actuation of a mechanism by the motion of A. This mechanism, shown schematically in the drawing, is designed to keep the weight B in its initial position until after the weight A has reached its lowermost position. A similar mechanism trips an arming device, when the weight B reaches its lowermost position.

Consider what happens if the whole mechanism is subjected to an extremely large acceleration for a very short time, as when dropped on a very hard surface. If the drop were made from sufficient height, the weight A would stretch its spring; but the deceleration would be completely over before the weight B was released, and the mechanism would not permit arming. For the mechanism to arm, the deceleration must be sustained long enough for the weight A to reach bottom and stay there while weight B executes its full stroke against the force of its spring. The safety of this arrangement can be shown by the following example. Assume springs of constant force. In the case cited it would take a minimum drop of 133 ft *onto a very special kind of surface* that would decelerate the mechanism at a uniform rate of $200g$ for 8 in. before the mechanism would permit arming. This compares to a drop of 8.5 ft for a simple single-element device, such as weight A with its spring alone.

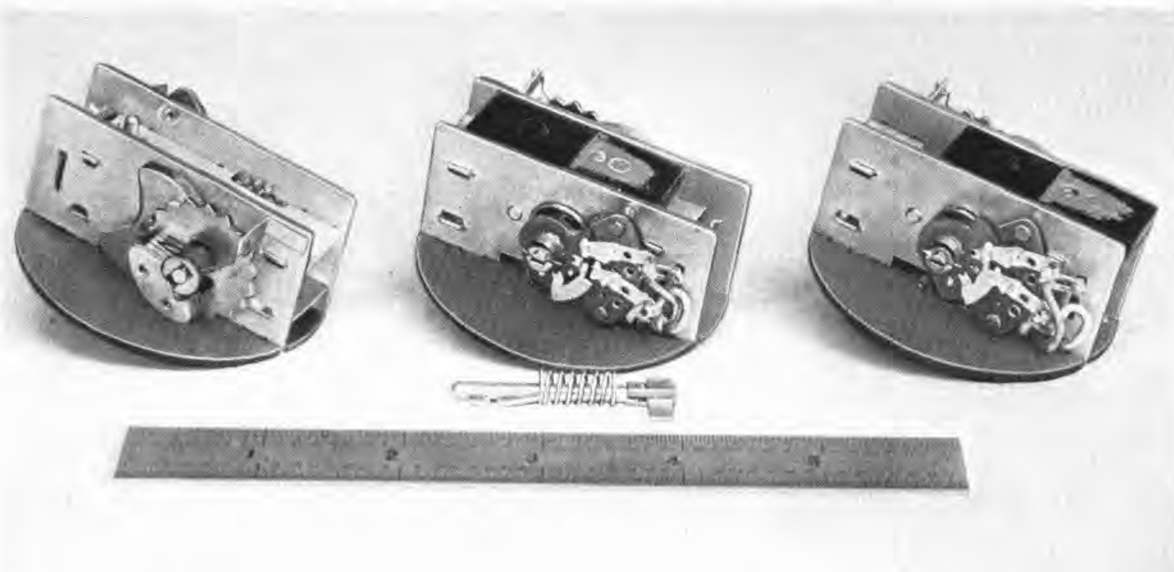


FIGURE 5. Arming device for T-5 fuzes. This device operates by integrating acceleration.

It is, of course, obvious that more than two weights can be thus interlocked and the safety multiplied accordingly. Three weights interlocked as above would require a minimum drop of 300 ft under similar conditions.

A practical device using this principle is shown in Figure 7, illustrating two unbalanced sectors, each maintained in its position by a 75-g spring. The flanges of the sectors are so arranged that the left-hand element must complete a 90-degree motion before the right-hand element can start. This mechanism, a switch designed for one of the early rockets, was tested by dropping from 100 ft onto a large variety of surfaces, from concrete to soft earth, without arming. It operated very satisfactorily

when fired in rockets with an acceleration of over $100g$. This particular device was not used on a large scale because its relatively short arming time (0.04 sec at $125g$) made it dangerous in case of motor blowups. A similar device was also designed for the T-132 mortar fuze. (See Figures 8 and 42.)

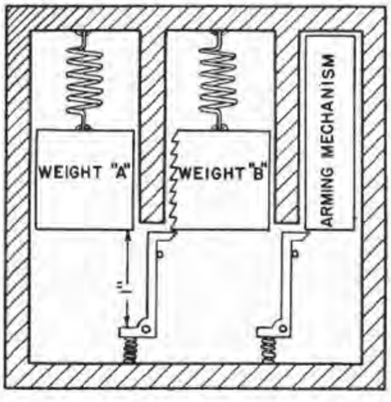


FIGURE 6. Double-action, acceleration-integrator, arming device.

Other types of acceleration integrators have also been proposed and tested. The use of dashpots was tried, but because of the general difficulties with the sealing of liquids and with temperature effects, this type of device was not used.

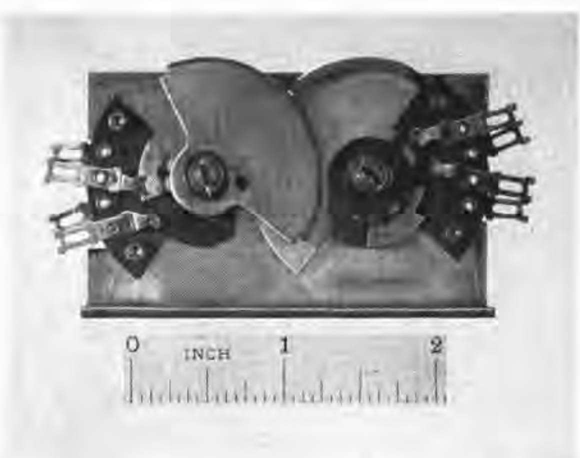


FIGURE 7. Photograph of double-action arming device.

4.2.4 Self-Destruction

When projectiles are fired over friendly territory or when, for the reasons of security, the number of duds reaching enemy territory must be kept to a minimum, SD is required. Two general methods of accomplishing this were employed. One was to use an electric circuit which detonated the fuze several seconds beyond arming. This method was described in Section 3.3.

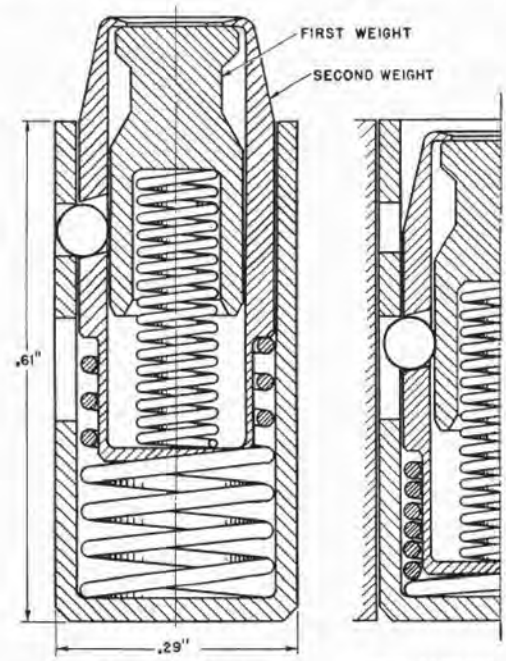


FIGURE 8. Arming mechanism for T-132. This is a double-action device.

The second method is to use a mechanical device which operated a contact accomplishing the same result. The mechanism that was used in a small number of T-5 switches manufactured by the Globe-Union Company consisted of a long coil spring which drove an escapement wheel for several revolutions after the completion of arming. One end of the spring was fastened to the frame, while the other was attached to the escapement wheel. The spring consisted of some fifty turns. At approximately three turns from the fixed end there was attached to the spring a small silver-plated contact. When the escapement made ten revolutions, this contact made only a part of a revolution, since the rotational speed of any element

[redacted]

of such a coil spring is proportional to its distance from the fixed end. In this way, speed reduction was obtained without the use of gears. A diagrammatical illustration of the mechanism is shown in Figure 9 and a photograph in Figure 10. In the T-2005 fuze a differential screw was employed to attain the same result. (See Figure 47.)

4.2.5 Impact Detonation

Throughout the history of the proximity fuze development, considerable controversy existed as to the desirability of including a mechanical impact detonating element in the fuze. Impact

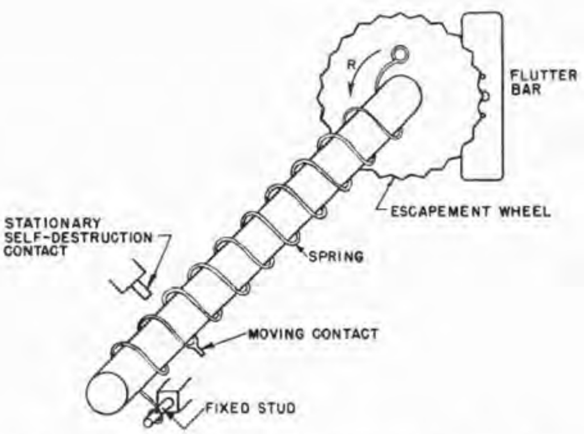


FIGURE 9. Diagrammatic illustration of self-destruction mechanism.

detonation, however, did not become a part of the formal military requirements (Ordnance Committee Minutes) until development of mortar shell fuzes was initiated (see Section 1.1). The arguments for the incorporation of this impact element is that in case of a failure of some electric component the fuze would still detonate the charge upon collision with the target or with the ground. This would serve both to increase the effectiveness of the weapon and to increase security by decreasing the number of duds. The objections to the use of an impact detonator are the greater complexity required in the fuze and the very great danger present when mechanical detonators are used, particularly so since the dud clearance problems encountered by our services were very severe.

One form of impact detonation which retains some of the advantages of overcoming duds consists of providing the fuze with inertia-operated switches designed to close the appropriate detonator circuits upon rapid deceleration of the projectile. This device is particularly useful when a large number of duds is due to the failure of electric components other than the power supply. A simple form of this device (for the T-6 fuze) is illustrated in Figure 11, where two leaf springs equipped with silver contacts are mounted on the forward plate of the switch mechanism and are arranged so as to provide direct connection between the deto-

FIGURE 10. Self-destruction element for T-5 fuze.

nator and the battery.[7] Only 100 of these switches were built before the work on the battery fuzes was terminated. The tests performed by the Army showed excellent results, with the switches operating properly upon ground impact down to an impact angle of 15 degrees. Such mechanisms can be made as sensitive as desired, and the only limitation is the drag of the projectile in flight. In the case of the M-8 rocket, this drag occasionally reached maximum values of $18g$.

4.3 MECHANICAL DESIGN OF PROXIMITY FUZES

4.3.1 Battery Fuzes

The first of the fuzes developed under the auspices of this division, for which definite

mechanical characteristics were specified by the services, were the battery fuzes for the M-8 rocket. The photoelectric and the radio fuzes were to be made interchangeable in all external respects. They were to fit a 3-in. fuze well 5 in. deep, and the nose contour was to be a continu-

FIGURE 11. Impact detonator for T-6 fuze.

ation of the rocket ogive. A photograph of the T-5 fuze is shown as Figure 12. The T-4 photoelectric fuze, which is described in Volume 3 (Division 4 STR) used the same battery, switch, and housing as the T-5.

Since the battery was to be easily replaceable, each of the fuzes was broken down into three separate components: the head or electronic assembly, the battery, and the safety and arming mechanism. The three parts were arranged to be connected by plugs and sockets.

The mechanical design of the head is rather simple. In the case of the radio fuze, the nose is made of mica-filled phenolic into which a small antenna cap is molded. In some of the fuzes this cap was spattered onto the surface of the phenolic. The nose is hollow and contains an oscillator block supported by a metal shelf below which are mounted the amplifier components. The base of this head consists of an insulating plate provided with pins which fit into corresponding socket holes in the top plate of the battery. The arming mechanism and arming switches are contained in a metal housing. The booster charge, which is a block of tetryl ½ in. long and roughly 3 in. in diameter, is contained in an appropriate compartment in the fuze housing directly below the arming switch.

The main features of the arming mechanism for this series of fuzes are as follows. The arming mechanism proper is energized by the acceleration of the rocket. This acceleration acts upon a small lead weight fastened to an escapement wheel which is retained by a 75-g coil spring. The motion of this wheel is controlled by a flutter bar. The arrangement can be seen in Figure 5. If the mechanism is acted on by an acceleration greater than $75g$ for a time longer than 0.15 sec, the lead weight reaches a position roughly 90 degrees from its starting point. This permits the operation of a spring-driven switch that closes the A and B power supply contacts, also shown in Figure 5. Upon cessation of the acceleration, the 75-g spring acting on the escapement wheel reverses its motion and moves a powder train interrupter carrying a tetryl lead into the armed

FIGURE 12. T-5 fuze, components and assembly. From left to right: electronic assembly designated as MC-382; battery power supply designated as BA-75; arming switch designated as SW-200; housing which contains tetryl booster; partial assembly of fuze; fuze completely assembled ready for installation in rocket.

position. Mounted on this interrupter bar is a small switch element that closes the detonator circuit near the end of the bar's travel. In this manner the fuze is not fully armed either electrically or mechanically until long after the cessation of acceleration. In most of the switches

built, this amounted to roughly 0.8 sec after the launching of the rocket.

A note about switch contacts should be made at this point. In many of the switches which preceded the production model described above, the contacts were mounted on leaf springs, as is the common practice in many relays and telephone jacks. It was soon discovered that these "pressure" contacts were extremely microphonic and caused malfunction of the fuzes because of the resultant electric noise. The rotary-type of radio switch that was finally adopted was far better in this respect. This was probably due to the fact that the contact pressures were somewhat greater and that the springs were extremely short, resulting in extremely rigid contact assemblies. Other types of contacts, particularly of the wedge-type, were also tested, but the availability of the type shown resulted in their exclusive use. Work on the engineering and the production phases of these arming mechanisms was done by the Globe Union Company of Milwaukee. Many variations of these switches were built by this company. They differed in the arming time, the value of acceleration for operation, the presence of impact detonating switch elements, the incorporation of SD, and many variations in the electric circuit.

The detonators for the fuzes were inserted into the arming switches through an opening in the top plate. This operation could be performed after the switch was completely assembled and tested. At the request of Army Ordnance an additional safety feature was later added which consisted of a key passing through the top plate of the switch. (See Figure 5.) The key was so arranged that if the mechanism, for some reason, began its arming cycle, the key could not be removed. This in turn prevented the switch from being plugged into the battery. If the arming mechanism was in the correct and safe position, the key could be easily removed and discarded. Of the hundreds of thousands of switches made, tested, and used, no case of malfunction resulting in an accident was reported.

Since the assembled fuze had to be capable of withstanding an acceleration of several hundred g, the components were required to pass a centrifuge test at $1{,}000g$. Large centrifuges were built for these tests by the National Bureau of Standards [NBS] and by the various contractors involved (see Figure 13).

4.3.2 Generator Fuzes for Rockets and Bombs

Early RRLG Fuze for Rocket Application

As mentioned elsewhere in this report the shortcomings of the battery were quite obvious to all concerned, and, shortly after the battery fuzes went into production, work was started on the use of air-driven generators for power supply. Since the efforts at that time were di-

Figure 13. Centrifuge for testing T-5 fuze.

rected toward the development of a fuze for the M-8 rocket, the generator and its driving system was designed to fit into the general pattern of the T-5 fuze; there was a strong effort made to use as many components of that fuze in its successor as possible. The obvious solution was to mount the generator below the head, in the space originally occupied by the battery, and to drive it by means of an insulating shaft connected to a windmill in the nose. Such an arrangement is shown in the *radio rocket longitudinal generator* [RRLG] fuze shown in Figure 14. The antenna still consisted of a small metal cap directly under the vane, all of the vanes used in these fuzes were of Bakelite.

The shaft connecting the windmill to the generator had to be of an insulating material so as not to short-circuit the antenna system. Cloth-filled Bakelite was found most suitable for this purpose.

At this time precision ball-bearings were not available in quantity, and in the first attempts to get satisfactory bearings for the high speeds involved, porous bronze (Oilite) bearings with steel shafts were used. These were acceptable in the generator but did not operate properly as nose bearings, primarily because of the thrust on the windmill and the large amounts of unbalance present. Home-made ball-bearing races were utilized with success (Figure 15).

In the rocket application, for which the first generator fuze was designed, the air velocities were limited to a rather narrow range between 800 and 1,500 fps, and no difficulties were experienced with excessive speeds of the generators. This was not the case later in bomb fuzes.

In connection with the RRLG the question arose as to whether the old plug-in arming system should be retained, operated only by setback, or whether advantage should be taken of the vane action and the arming be made dependent on both acceleration and air travel. Since the emphasis on the safety of the proximity fuzes at the beginning of World War II was perhaps inordinately large, it was decided to abandon the pure setback mechanism and to employ a safety device which would not arm unless acted upon by both air impact and acceleration. The RRLG fuze, or T-12 fuze (Ordnance Department nomenclature), was not manufactured on a large scale because, at approximately the time the design was completed, further work on the M-8 rocket was stopped. The general philosophy, however, of combining air drive with setback was carried over into all the later fuzes. Bibliographical references dealing with this fuze are NBS reports on RRLG or T-12 and reports of the Rudolph Wurlitzer Company.[74]

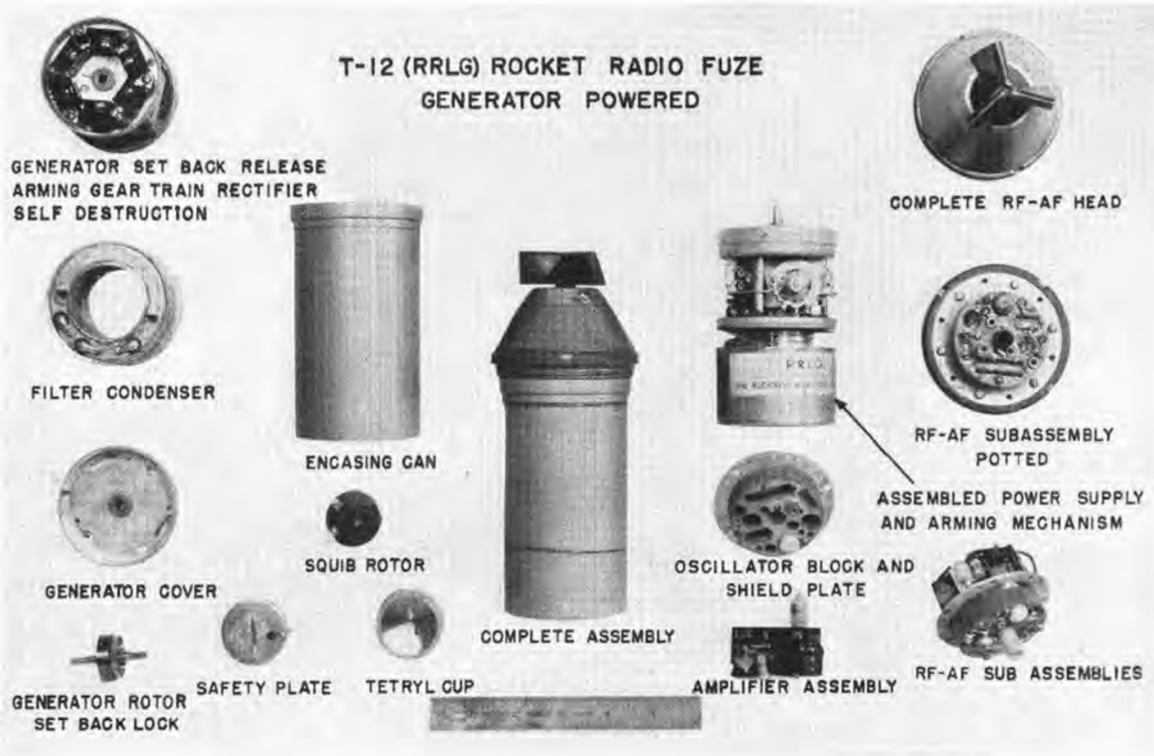


FIGURE 14. T-12 fuze, complete assembly and principal components.

T-50 Bomb Fuze

Overall Design Details. The next requirement for a proximity fuze was for a generator-operated fuze for bomb use. Since the head and the generator as used in the RRLG appeared to be satisfactory, they were incorporated into

Figure 15. Vane and vane bearings for generator-powered bomb fuze.

the T-50 series of fuzes but with some changes in the arming system and the overall exterior shape in order to adopt them to bomb use. The nose fuze well of most of the American bombs used a 2-in. thread; therefore, an adapter case, which because of its general physical appearance became known as the "potato masher," was designed to house the entire mechanism.

A photograph of a cutaway of a typical T-50 fuze is shown in Figure 16. As can be seen, the general arrangement is similar to that of the RRLG fuze in that the electronic components of the nose are followed by the power supply and the arming system. The rectifiers for the power supply are mounted in the Bakelite housing surrounding the reduction gear, while the filter and firing condensers are made in a tubular shape and mounted in the space surrounding the low-speed arming shaft. The vanes, or windmills, originally used in the T-50 were made of either cotton flock or rag-filled phenolic materials. It was found that such vanes could withstand rotational speeds up to 80,000 rpm without bursting. Some of the cast Alnico generator rotors could not withstand such high speeds, and it was necessary to perform a large amount of high-speed testing. An ultra centrifuge was developed for this purpose at NBS and was adopted by many of the manufacturers of Alnico rotors and of the fuzes (see Figure 17). The rotating system of this ultra centrifuge is an air-supported turbine rotor capable of speeds in excess of 120,000 rpm.

The original windmills had three blades of 2-in. overall diameter; however, when they were released at high altitudes and at low plane velocities, the rotational speeds did not repeat well. Therefore, the design was changed to a $2\frac{1}{2}$-in. windmill that had considerably larger power output, resulting in more reproducible speed. Since the bomb velocity varied from approximately 200 to 900 fps, the speed of the vane varied over a corresponding range. This resulted in extremely high top speeds; since

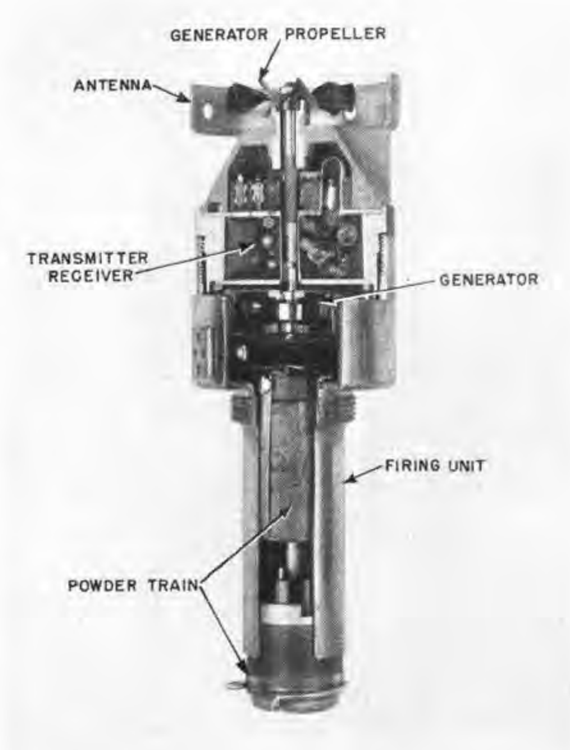


Figure 16. Cutaway of typical T-50 type bomb fuze.

dynamic balancing was not employed in the initial production of these fuzes, great difficulties arose due to the failures of bearings and the presence of microphonic noise.

Several lines of attack were followed to overcome these difficulties. One concerned the use of interchangeable windmills that could be eas-

ily changed in the field in order to select the type most suited to the plane speed and the bombing altitude. Another involved the balancing of the vanes to eliminate vibration and thus permit the use of a single high-speed windmill for all applications. It was found that the interchangeable units could not be easily balanced, and this method was soon abandoned.

FIGURE 17. Ultra centrifuge for testing rotors for T-50 type fuzes.

One interesting by-product of the plan to use interchangeable turbines was the special T-50 shipping can with a special container built into its cover for one or two spare units. This additional space later proved itself very convenient for packaging the T-2 extended arming device which, in fact, was specifically designed to fit this package.

Dynamic balancing will be discussed at the end of this chapter (see Section 4.6).

In the first bomb fuzes the antenna still consisted of a small streamlined cap directly below the vanes, but for electrical reasons it was soon changed to a thin ring approximately 3 in. in diameter that was supported by four buttresses extending from the nose section, as seen in Figure 18. A short time later the ring was lengthened to approximately $\frac{3}{4}$ in. (see Figure 16) and this was the antenna that, with minor variations, was carried into all the later fuzes of this general type. (See Section 2.7.6 for electrical reasons for increasing length of ring.) This longer antenna ring also performed several useful mechanical services. It acted as a guard for the vanes and at the same time provided a convenient anchorage for the vane locking pins and extended arming devices.

The enclosing of the windmill in a long antenna ring also gave rise to the possibility of using metal vanes. Successful tests were made, and shortly thereafter most of the manufacturers changed to the use of stamped steel 10-bladed windmills. Some difficulty was experienced with metal fatigue and breakage of the blades, but this was rectified by the use of ribbing at the thin section near the root of each blade (see Figure 19). These windmills were also dynamically balanced in production. Until very near the end of the T-50 program the vane shafts were equipped with ball bearings of the type shown in Figures 15 and 18B. The races were machined in steel and case-hardened. The balls were of the quality used in precision bearings. Because of the absence of thrust and of the inherently better balance, the generator bearings were of the simple sleeve variety. The shafts were of stainless steel, while the bearings were of porous bronze, commercially known as Oilite. Near the end of World

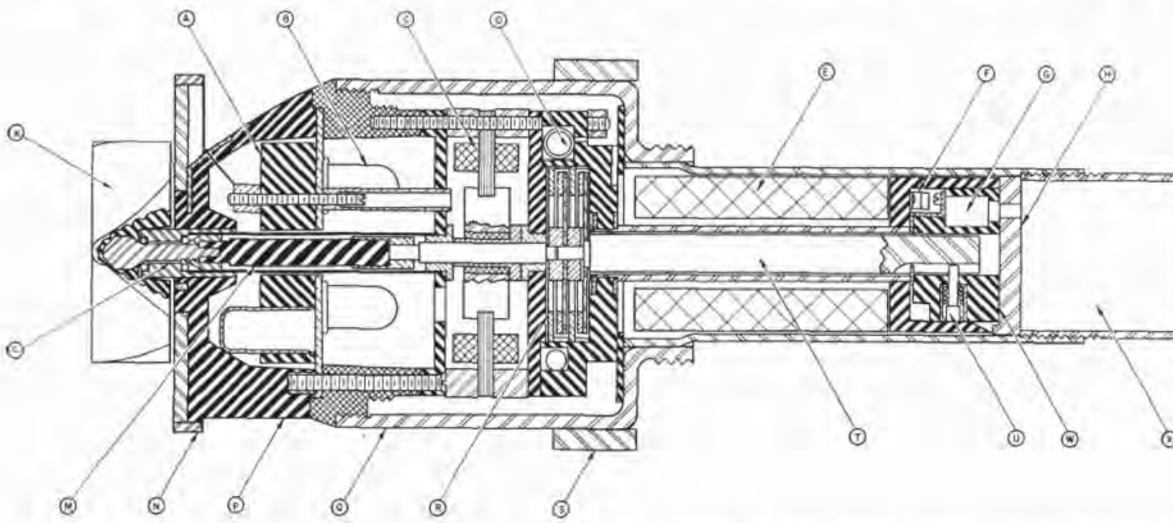
FIGURE 18A. Photograph of assembled T-50 type bomb fuze.

War II most of the manufacturers began to use precision ball bearings, both for the turbines and in the generators.

In the original design of the T-50, the coupling shaft, that is, the shaft coupling the windmill to the generator, was loosely coupled at both ends. The engineers of the General Electric Company suggested and experimented with a design in which the coupling shaft was rigidly attached to the windmill but was loosely coupled only at its bottom end. This required only one ball bearing at the nose instead of two. The design was generally adopted and its use resulted in a simpler, more rigid, and more economical assembly.[17] It is shown in Figure 16.

Experiments at Bowen[75] and at the National Bureau of Standards[18] showed that noise was

still caused by the looseness of the coupling between the insulating shaft and the generator. Experiments were performed on the use of rubber and other flexible materials as vibration absorbers at this point. A final design was evolved in which the generator was driven through a tight-fitting rubber coupling. This also served to minimize the rotational oscillations of the generator rotor that had caused phase modulation in the generator output. This, in turn, modulated the voltage output of the wires were employed to hold the vanes and the arming mechanisms in the "safe" condition (see Figure 20). After release, the windmills were required to make a definite number of turns to arm the fuzes. The electric arming of the generator fuzes was considerably simpler than that of the battery fuze, since no A or B switches were required. In the original RRLG rocket fuze, SD was a requisite, and the gear train was, therefore, arranged to continue its operation after the explosive train was aligned.



A Oscillator block
B Amplifier
C Generator
D Rectifier
E Filter condenser
F Contacts to detonator
G Detonator
H Tetryl plate
K Windmill
L Vane bearing assembly
M Drive shaft
N Antenna (in later models, antenna extended forward to enclose vane)
P Insulating support for antenna
Q Fuze housing ("potato masher")
R Speed reducing gears
S Lugs for wrench
T Low-speed drive shaft for arming mechanism
U Locking pin for detonator rotor
W Detonator rotor (arming consists of rotation of this piece into proper position)
X Booster cup

FIGURE 18B. Sectionalized drawing of T-50 type bomb fuze. Same general arrangement of parts used for all ring-type bomb fuzes.

power supply when the latter was operated on the steep part of its voltage-versus-speed regulation curve.

Some further reduction in mechanical noise could have been obtained by dynamic balancing of the generator rotors, but because this would have necessitated major changes in the assembly, it was not resorted to in the T-50 and T-30 series of fuzes.

The Arming System. Since bombs experience no acceleration of large magnitude, arming An SD contact was arranged to close the detonator circuit at the desired time after arming. This feature of a continually running gear train was carried over into the bomb fuze, since the possibility of converting them back into rocket fuzes was always present.

From the point of view of noise and microphonics, it would have been better to design the gear train so that it would be disconnected from the vane at arming, and several methods of doing this were, in fact, suggested, but the

[redacted]

possibility of requiring SD and the availability of the gear train (from the RRLG program) together with the ever present pressure of time kept the mechanism as it was. The first gear trains used in the T-50 series of bombs

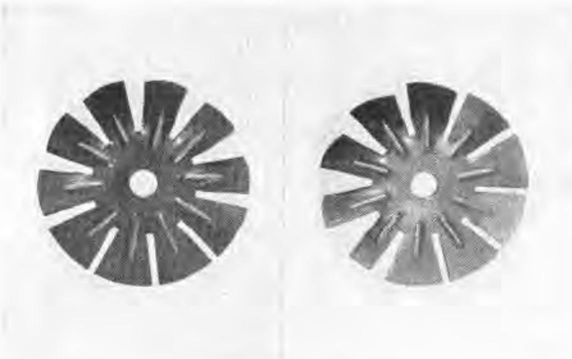


FIGURE 19. Unfinished windmill for T-50 bomb fuze, showing flutings for increased rigidity.

were of the planetary-differential type. A photograph of this gear train is shown in Figure 21. This differential gear appeared particularly desirable for these mass-produced fuzes because of its simplicity and cheapness. It was designed originally for the RRLG rocket fuze, for which speeds in excess of 30,000 rpm were not expected, and no serious trouble with noise or short life was anticipated. This, however, did not prove to be the case in the bomb application. These gears suffered from several grave defects. One was their short life under high speeds of operation, and the other was the large amount of noise and vibration they introduced into the fuze.[3] In order to overcome these difficulties, a worm type of gear reduction, which fitted the space allotted to the differential gear, was designed (see Figure 22). The only change necessary in the fuze for its adoption was a change in the generator shaft, which now incorporated a worm at the first step of the gear reduction. These worm gears, which were engineered by the Globe Union Company[51] and produced by them and several other contractors, were used in all of the bomb fuzes with excellent results. The overall reduction in speed from the windmill to the arming shaft was approximately 5,800 to 1.

A rather radical departure from the previous arming systems was introduced into the method of interrupting the powder train. Instead of keeping the electric detonator in a fixed position and moving a slider containing one of the other powder train elements, it was decided that considerable increase in simplicity and dependability could be achieved by moving the electric detonator itself so as to interrupt both the explosive train and the electric firing circuit. A small Bakelite drum was arranged to be driven by the low-speed shaft of the gear train. This drum carried the detonator with

FIGURE 20. Use of arming wire and locking pin to prevent vane rotation.

its two electric contacts and a small transfer pin which acted as a coupling between the drive shaft and the drum and also served as a lock for the detonator assembly when in the armed position. Since the gear train ran continually before and after arming, SD could be achieved by the insertion of a special washer under the detonator drum in order to ground the thyra-

tron plate circuit and thus fire the detonator.

FIGURE 21. Planetary-type speed-reducing device for T-50 fuzes.

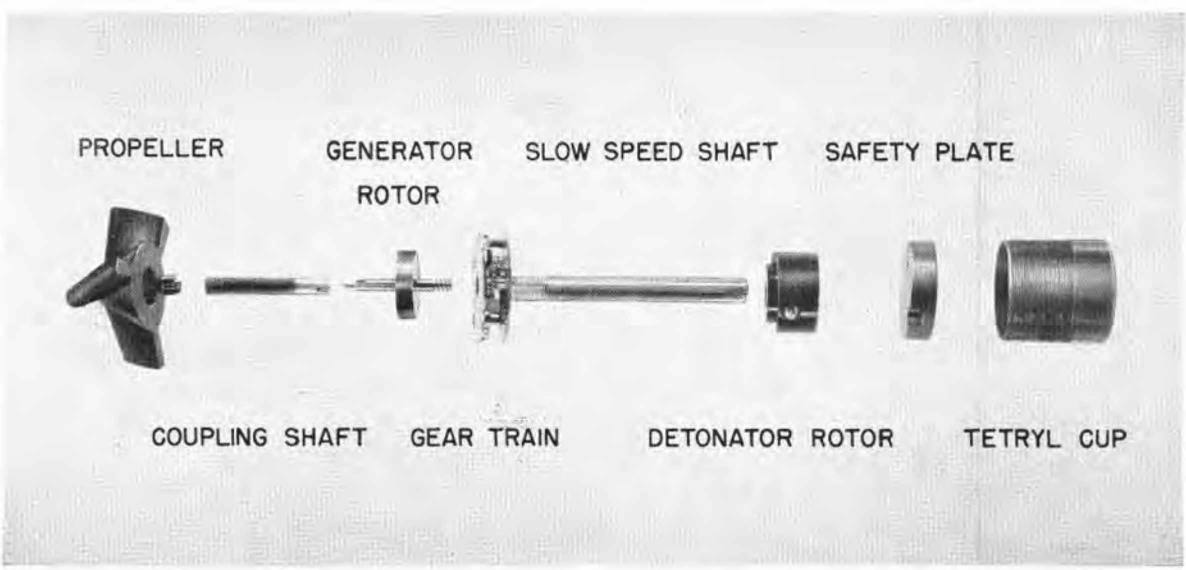


FIGURE 22. Arming mechanism of T-50 type fuzes with worm gear.

Because of the direct relation between the vane speed and the velocity of air travel, the distance through which a bomb fell before arming was easily controllable by a change in the angular setting of the detonator rotor. The only limitation on this was the fact that the detonator had to be at least 60 degrees away from the tetryl lead in the safe or unarmed position. This limited the unarmed angle setting, called the arming angle, to the range of more than 60 degrees and less than 300 degrees. Angles from 100 to 180 degrees were most commonly used in practice.

The electric connections to the detonator were made through two phosphor bronze or beryllium-copper leaf springs mounted in the detonator rotor housing. These silver-plated springs made contact to two small silver-plated screw heads, under which the detonator leads were fastened. The system of contacts described above had several serious faults: the springs could be easily deformed in handling so as to result in poor contact, and the transfer pin had to be rather carefully made because if it failed to snap out of the slot in the shaft and lock the detonator rotor into its armed position, the rotor would turn through the armed position and cause the fuze to be a dud.

The exact length of air travel to arming could not be exactly preset because the manufacturing tolerances in this assembly were such that small erorrs could cause large differences in the arming distance. Some of the fuzes produced near the end of the program were set by manual or automatic counting of windmill turns. This difficulty was not anticipated in the design because the need for precision arming

of the proximity fuze was not expected. It was thought that merely delaying the arming for an approximate distance would be sufficient. The using services, however, laid down rather stringent requirements during the course of the development program, for the minimum and maximum limits of safe air travel, and several minor modifications in the arming systems were introduced as a result.

A removable safety pin similar to the key of the T-5 switch was added to the arming system of the T-50. This pin had to be manually removed before the fuze could be screwed into the bomb well. This pin indicated that the detonator rotor was in the safe position, and it could also be used as a later check if, for some reason, the fuze had to be removed from the bomb after a flight. The details of this safety system are shown in Figures 23 and 24.

FIGURE 23. Safety pin installed in T-50 type fuzes. Pin is removed before fuze is inserted in fuze well.

T-51 BOMB FUZE

A modification of the T-50 fuze was made by changing the antenna to one of the dipole variety (see Figure 25). The mechanical arrangement was almost exactly identical to that of the T-50 except that plastic windmills were used to the end of production. This fuze was later manufactured as the T-51 fuze by the Zenith Radio Corporation (see Figures 26 and 27).[71] The final model of T-51, which carries a bracket for the vane locking pin, is shown in Figure 5 of Chapter 1.

Several types of dipoles were experimented with at the National Bureau of Standards. One was the metal type molded into the antenna head, and the other consisted of plastic dipoles, made integral with the head, over which a conducting surface of metal was either plated or spattered. Metal dipoles were used by the Zenith Corporation in their production.

T-82 BOMB FUZE

A markedly different bomb fuze, the T-82, was developed by the Westinghouse Company.[68] (See Figure 28.) In an effort to overcome the vibration difficulties encountered in the design of the T-50, the rotating system of this fuze was located in its base so that it could be nearly totally enclosed by the fuze well. By using a radial flow turbine mounted directly on the shaft of the generator and supporting the whole high-speed assembly by a metal casting mounted in the nose of the bomb, an extremely rigid and quiet mechanical design was achieved. The air to drive the turbine was conducted through the electronic components by a central duct and exhausted through two wide ports near the base of the fuze. The main body of the fuze was made of mica-filled phenolic and was

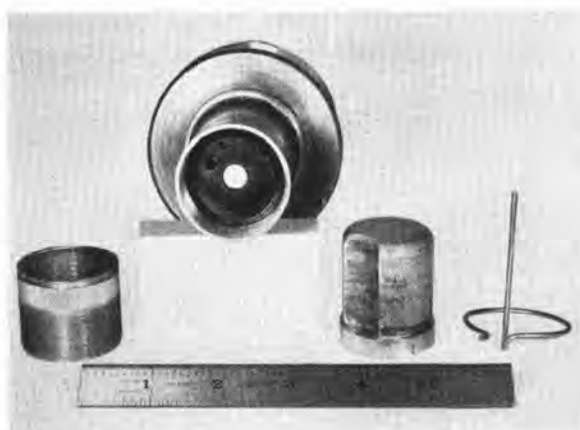


FIGURE 24. Details of arming safety pin device.

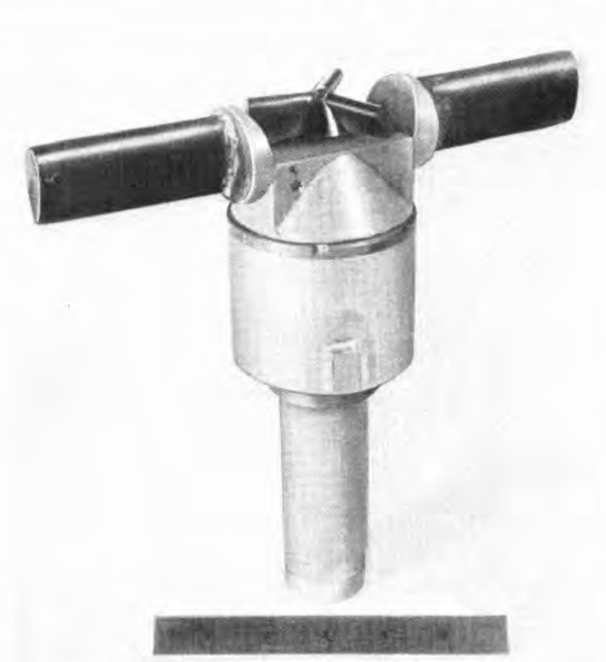


FIGURE 25. Early model of T-51 fuze.

connected electrically to the power supply and the arming system by means of a multiple pin plug. These two main assemblies were held together by four screws. The gear reduction was of a worm type similar to that used in the T-50, and the arming system was identical.

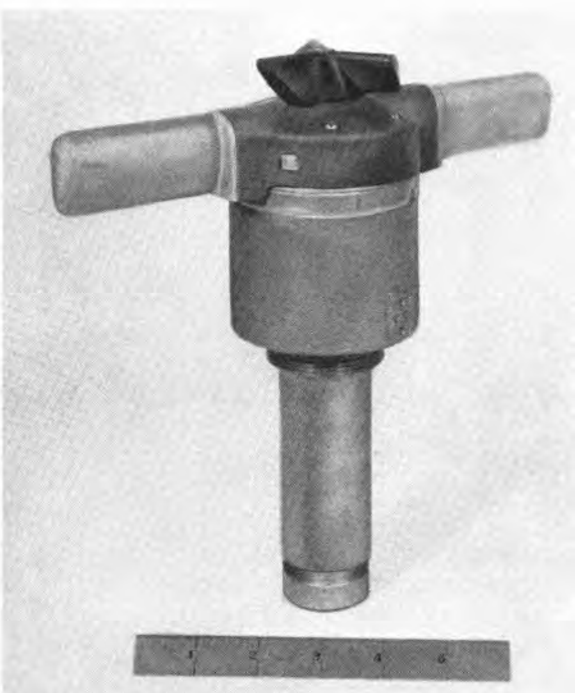


FIGURE 26. Later model of T-51 fuze.

No dynamic balancing was employed in this fuze, but precision ball bearings were used in all models. In order to limit the top speed of the turbine, automatic speed regulation of several kinds was tried, and it was found that, by making the blades of the turbine of spring steel, they could be made to change their curvature, or pitch, when acted upon by both centrifugal force and air pressure. The production

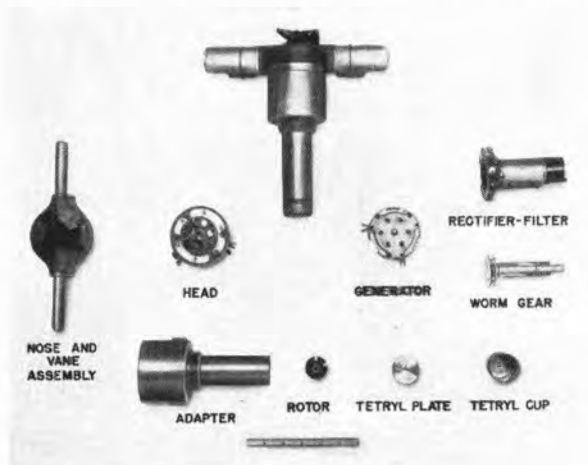


FIGURE 27. Assembly and principal components of T-51 fuze.

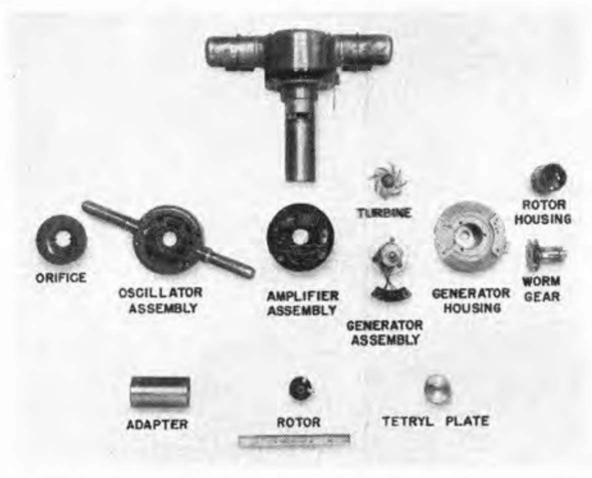


FIGURE 28. Assembly and principal components of T-82 fuze.

model of the fuze employed four rigid and four flexible plates, shown in Figure 28. It was found in practice, however, that the range of speeds over which this fuze operated did not result in any speed regulation of this particular turbine, but the top speeds did not cause any trouble, because of the excellent bearings used.

train was, therefore, developed at the National Bureau of Standards, which was again designed for production and produced by the Globe Union Company. Figure 29 shows the construction of this gear train, and again only the main features of its operation will be stated. For proper arming the mechanism requires a sustained acceleration of more than

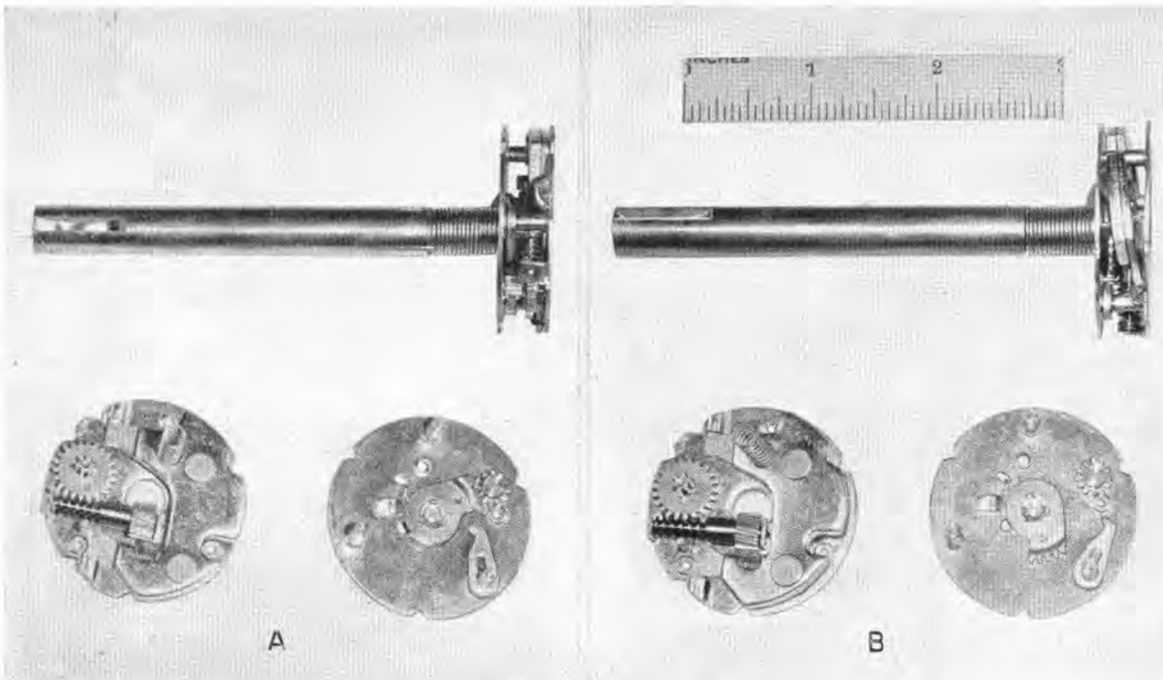


FIGURE 29. Arming device for T-30 and T-2004 fuzes. A, parts in their normal position; B, inertia element in position assumed during setback.

4.3.3 Generator Rocket Fuze T-30 (and T-2004)

As mentioned previously, work on the M-8 rocket was discontinued, and emphasis was placed on the use of the fin-stabilized Navy rockets developed at the California Institute of Technology. It was quite apparent that with slight modifications the T-50 bomb fuze would serve excellently on these projectiles. With a minor change in the vane pitch, the fuze could have been used "as is," but the presence of reasonably large values of acceleration offered attractive possibilities of increasing the safety of the arming mechanism. A new type of gear

$10g$ occurring simultaneously with the rapid motion of the fuze through air for 300 ft. The windmill is locked by the usual arming wire, when the rocket is in its launcher. If this arming wire were prematurely withdrawn, the windmill would start rotating, but due to the absence of acceleration the mechanism would jam, one of the brass gears would strip, and the fuze would become a dud if fired.

The arming system was further designed so that the mechanical and electric arming was not completed until after the cessation of acceleration. This was done to prevent the fuzes from being set off at some point beyond the 300 ft by the burning of the propellant. The

RC arming delay which followed the completion of the mechanical arming cycle increased this safety still further.

Since this gear train was so designed that the

FIGURE 30. Doughnut arming device installed in fuze.

low-speed shaft did not rotate after the completion of mechanical arming, no SD was incorporated into the T-30 and the T-2004 fuzes. For the same reason, the detonator rotors were not provided with a transfer pin but were permanently locked to the low-speed shaft.

The T-30 and the T-2004 fuzes were primarily designed for stop-gap use, while the development of special rocket fuzes was in progress (see Section 4.3.4 on T-2005) and the setback gear train was designed with this in mind. The major objection to the modified bomb fuzes as rocket fuzes was their size, which measurably increased the drag on the missile. The use of arming wires in rocket fuzes was considered objectionable by NBS engineers, and the employment of a setback mechanism that could not be inspected from the outside and that resulted in a dud in case of malfunction of the arming wire was not considered an elegant solution.

The British Air Forces requested Division 4 to design an arming mechanism that would convert a T-50 into a rocket fuze but that would keep the vane from turning and release it only by the action of setback. No arming wires were to be required and no loose components, such as

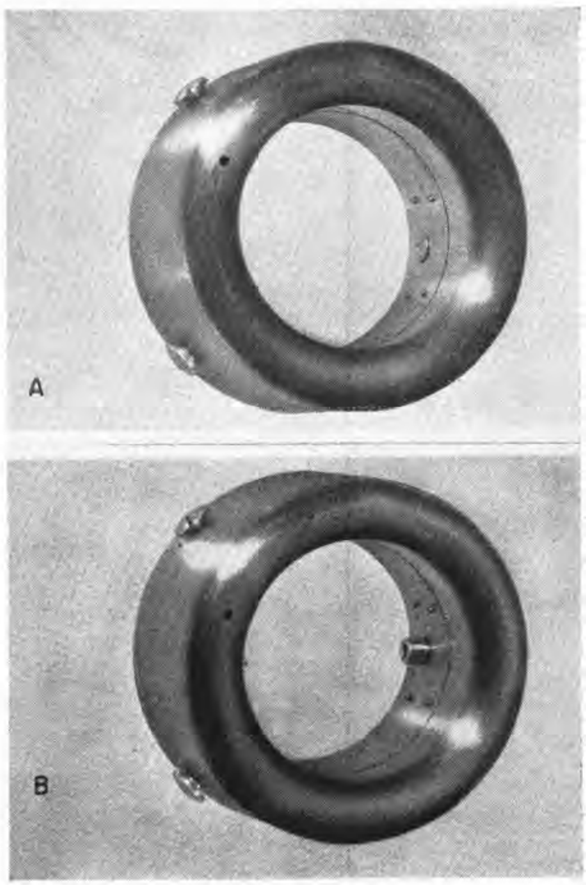


FIGURE 31. Doughnut arming device for rocket fuzes. A, plunger in armed position; B, plunger in unarmed position where it prevents rotation of vanes.

pins, were to be released in flight. Accordingly, a "doughnut" arming mechanism was developed.[41] This mechanism, shown in Figures 30 and 31, fitted inside the antenna and held the vanes in the locked position by a small pin. A

flutter type of mechanism was enclosed in the ring and, when subjected to an acceleration of more than $10g$ for more than $\frac{1}{4}$ sec, caused the release of the vanes. The engineering and production of this unit was done by the Transition Office of NDRC and by the Solar Aircraft Company of California. An interesting feature of this device is the circular flutter weight, with its center of gravity on the center line of the fuze. This made the mechanism operable in the presence of slow rocket spin (about 1,000 rpm, the spin rate of one of the British rockets for which the mechanism was designed). The use of the ring-shaped weight enabled its designers to obtain a large moment of inertia with a minimum of total mass. This device was able to pass the standard jolt test without difficulty.

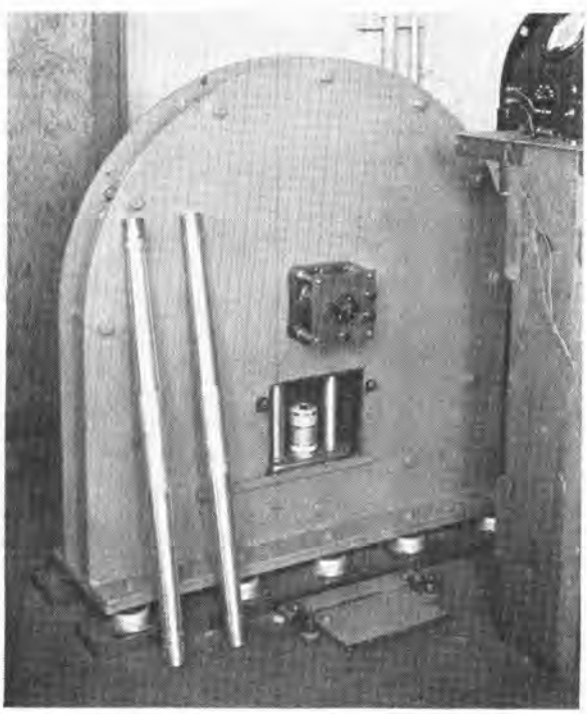


FIGURE 32. Front view of high-g centrifuge for testing mortar fuzes.

4.3.4 Miniature Fuzes for Trench Mortars and Rockets

FUZES, T-132 AND T-171

When Division 4 undertook the development of a generator proximity fuze for trench-mortar use, completely new problems of mechanical design arose. The accelerations experienced by a mortar shell are of entirely different magnitude from those to which the physicists and engineers were accustomed in their work on

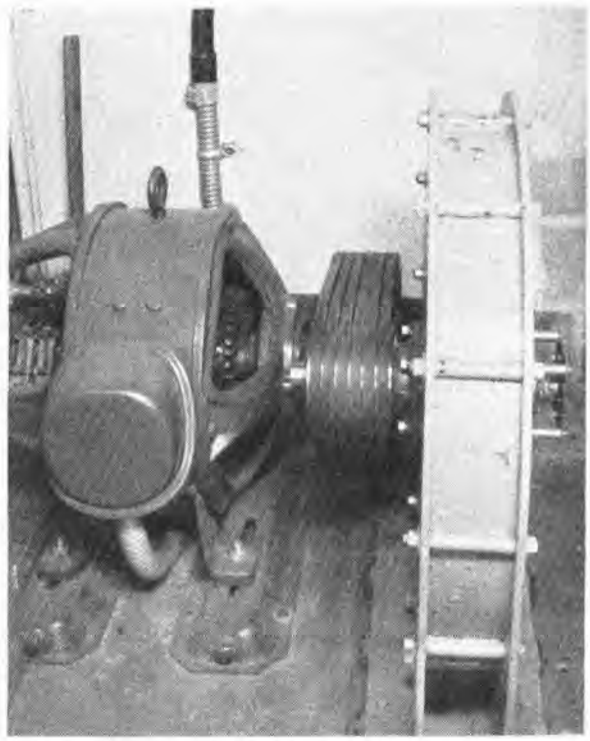


FIGURE 33. Side view of high-g centrifuge for testing mortar fuzes.

bombs and rockets. An 81-mm mortar shell is fired from its gun with varying accelerations up to $6{,}000g$. The resulting stresses obviously required a new approach to the mechanical design of the proximity fuze. This point in the fuze program represented a welcomed opportunity for incorporating into the new fuze a great many of the suggestions and ideas which were gathered in the previous work.

New testing techniques had to be developed for this work. Although it is practically impossible to duplicate the gun accelerations in the laboratory, a close approximation can be made by using a special centrifuge. Accordingly, NBS designed and built a high-g centrifuge capable of testing complete mortar fuzes at accelerations up to $15{,}000g$. Photographs of this equipment are shown in Figures 32 and

33. Two Dural arms, such as are used in the machine, can be seen in the photographs.

The requirement for extreme compactness presented, besides the mechanical problems, the problem of securing a sufficiently large antenna to insure adequate r-f loading. In order to accomplish this, the usual arrangement of the antenna and ground of the proximity fuze was reversed. It was decided to make the body of the fuze the ground, and to use the vehicle as the antenna. This, of course, is merely a juggling of words, but it helps to explain how, for a fuze of a given size, a better arrangement can be made by locating the antenna insulator directly ahead of the nose of the projectile and mounting as many of the mechanical and electronic components of the fuze as possible ahead of this antenna "break." A diagram of the general arrangement of the resulting fuze is shown in Figure 34.

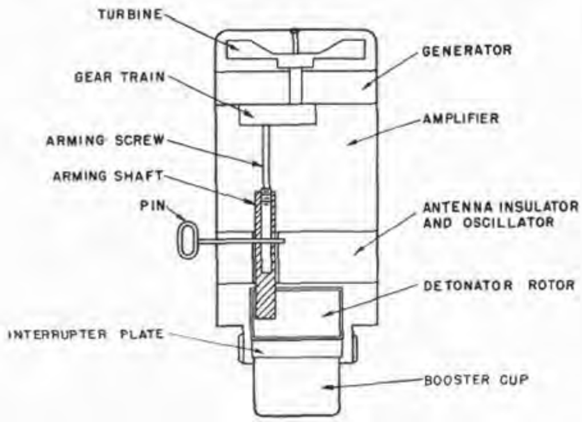


FIGURE 34. Diagram showing arrangement of principal components in T-132 and T-171 fuzes.

The possibility of using a base generator, as was done in the case of the T-82, was seriously considered but was discarded because of the considerable space occupied by the air passages. Accordingly, the turbine and the generator were mounted in the forward end of the fuze. The decision to do this was further strengthened by the requirements that the fuze operate at very low airspeeds. In the case of a 0 charge, the 81-mm shell leaves the gun at approximately 150 fps, making the successful operation of the turbine difficult. More will be said about this matter in connection with the T-172.

The generators used in the experimental trench mortar fuzes were originally identical with those designed by Zenith for the T-50, with the exception that the six corners of the stator were machined off, giving a circular stator with an outside diameter of 2 in. It was found that the removal of the corners did not reduce the output of the generators. This six-coil design was adopted by the Globe Union Company in their production of the T-132.[50] The Wurlitzer Company, however, because of their experience with the wave-wound T-50 generators decided to experiment with a double snake-wound generator of somewhat smaller size (see Figure 35). This design, when used with a voltage doubling rectifier circuit, proved quite satisfactory.

The problem of supporting the coils and laminations against the force of setback was met by centrifugal potting of the stator, using a special high-temperature potting compound (see Section 4.7). The stator of the generator was enclosed in a thin metal shell, and the whole assembly was rotated about the central axis of the generator at approximately 7,000 rpm. A measured quantity of the hot potting mixture was poured into the generator frame.

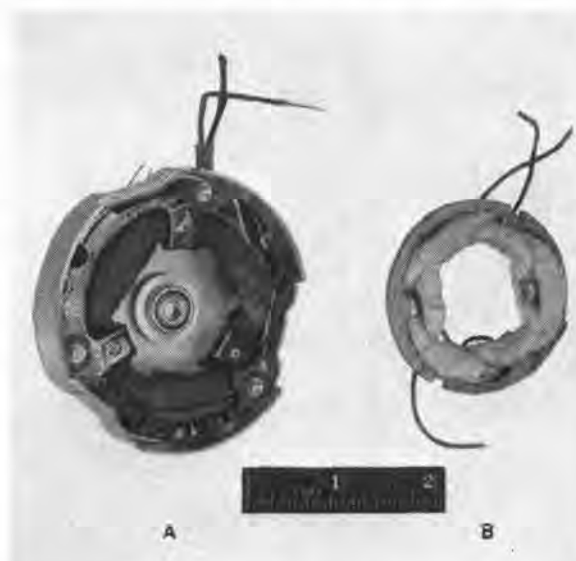


FIGURE 35. Generator stator for T-171 fuze (right) shown in comparison with stator for T-50 fuze (left).

The centrifugal action forced the liquid to spread into the space around the coils and form a cylindrical inner surface just back of the pole faces. The material was cooled while still spinning at the high rate.

The dynamic balancing of the high-speed rotating system eased the problem of the bearing design very greatly. Precision bearings

FIGURE 36. Protective cover and arming pin for T-132 fuze.

were incorporated into only a small number of fuzes. It was found that the New Departure R-3 ($\frac{1}{2}$ in. OD, $\frac{3}{16}$ ID) was capable of withstanding a static thrust of nearly 1,000 lb and then was able to operate at 100,000 rpm for several minutes without failure. The procurement problem was still very serious and since experiments indicated that sleeve bearings, particularly of the Oilite-type, could be employed satisfactorily, the Globe Union Company did considerable research on their use. The engineers of the Allis-Chalmers Company in Milwaukee urged the adoption of rubber mounting of the bearings, since their experience with the high-speed rotating machinery indicated that some form of damping was required for these bearings. The Globe Union Company adopted this suggestion, and the use of rubber mounting for the sleeve bearings was standard in all of their production of the T-132.

In the summer of 1945 the University of California was asked by the Transitions Office of NDRC to pursue further the research on the bearings and rotating components for the mortar fuzes. This group found that shafts with extremely hard surfaces were suitable for this service.[60] The National Bureau of Standards also conducted research in the same field and had excellent results with bearing assemblies in which both the shaft and bearing were made of identical and very hard materials. Some Nitralloy bearings mounted in rubber were run at speeds in excess of 75,000 rpm continuously for an hour without failure. This was all the more amazing, since the bearings were not lubricated in any manner whatever.[25]

The high-speed joints of the T-50 were eliminated by the single unit rotating assembly consisting of a turbine, the generator rotor, and the high-speed shaft. Since dynamic balancing required the removal of metal in two planes, a brass disk of approximately $\frac{1}{16}$-in. thickness was fastened below the Alnico rotor. The under side of the turbine and this brass disk provided two convenient surfaces for the easy removal of mass. A special dynamic balancing machine for this purpose will be described in Section 4.6.

The arming system of the T-132 fuze in the original form was to be operated by the impact of air so that the fuze would arm after the maximum possible air travel. Calculations showed this to be approximately 400 yd. This would permit the fuze to be fired at 0 increments and 45-degree elevation, with the arming occurring a very short distance before impact.

A manually removable safety pin was provided, as shown in Figure 34. This pin was intended to prevent accidental arming of the fuze but had to be removed and thrown away in accordance with the customary use of the standard trench-mortar mechanical fuzes. In the final T-132 designs, a protective plastic cover was shrunk over the front end of the

fuze, and the removal of the pin and the cover was accomplished by one motion of the hand. Photographs of the arrangement are shown in Figure 36.

Several departures from the bomb and rocket arming techniques were made in the details of the arming system. The detonator was still carried in a detonator rotor mounted above an interrupter plate. It was maintained in its safe position by an arming shaft, which was withdrawn by the action of a screw driven by the turbine through a reduction gear train. Its movement, however, was not slow as in the case of the bomb and rocket fuzes. Instead the detonator rotor was snapped into position by a coil spring. In the T-132 the arming shaft was made of Bakelite so as not to short-circuit the antenna system. It was enclosed in a metal shielding tube for as great a part of its length as possible. In the T-171 a metal shaft was used; a short circuit at the antenna was prevented by a snap-out motion of this shaft, rapidly withdrawing it from the antenna insulator at the moment of arming.

FIGURE 37. Jolt machine for testing proximity fuzes.

The original design of the detonator rotor provided an additional space for a mechanical impact detonator element, but because of the very great danger in using this element, it was not built into the first production of the fuzes. Instead the space was occupied by a double-element safety pin which held the rotor in a safe position unless released by a sustained acceleration of over 1,000g (see Figures 6 and 38). This additional safety was necessitated by the requirement that the mortar fuzes be able to pass the jolt test. This test consists of mounting the fuzes by their base threads into a machine-driven arm that is subjected to a free fall of approximately 3 in. onto a rather hard surface for a total of 5,250 drops (see Figure 37). The fuzes were held in each of three positions for 1,750 drops each. It was found that the first T-132 and T-171 fuzes built would not pass this test but failed by breaking at the antenna insulator. With the arming system as originally designed, this resulted in the withdrawal of the arming shaft and the rotation of the detonator into the armed position. Since the electric detonators are quite safe against mechanical shock at handling, this did not necessarily represent a serious hazard. However, the addition of the double-element safety pin eliminated even this danger by keeping the rotor in the safe position in case of accidental withdrawal of the arming shaft.

Still another version of the arming mechanism for the T-132 and T-171 series of fuzes was designed just before the end of World War II. In an effort to increase the unarmed air travel, a clock mechanism was substituted for the gear train. This clock mechanism, shown in Figure 38, was mechanically coupled to the detonator, and the whole assembly occupied the space originally filled by the detonator rotor. The detonator was held in the safe position by the double-element setback pin described above for the original rotor. Upon its release the detonator was moved into position and was electrically and mechanically armed 10 sec after firing. This resulted in an automatic increase in the safe air travel when the shells were fired with the greater number of increments, because the air travel to arming now was directly proportional to the velocity of the shell.

Another great advantage of using this clock rotor was the elimination of the gear train and arming shaft. This permitted the power supply to be completely isolated mechanically from the rest of the fuze so that excellent sealing of the electronic components against moisture became possible. The elimination of the gear train with its arming shaft also meant considerable reduction in mechanical vibration and noise.

FIGURE 38. Clock mechanism for arming mortar fuzes. Pin assembly in lower right-hand corner is common to all fuzes developed for mortar shells. It is a double-element inertia device.

Raymond Engineering Laboratories were asked to do the engineering and the experimental production of the clock rotors.[57] Several completely satisfactory working samples were received from them shortly before the conclusion of hostilities.

Another expedient which was experimented with for delaying the arming of the fuze for as long a time as possible was the use of a small dashpot switch; a cross section of this is shown in Figure 39. The switch would be placed into the detonator circuit and would normally be kept closed by the coil spring. The detonator would, however, be kept unarmed by the regular clock rotor. Upon firing, the sliding piston contact would move back for a distance proportional to the time integral of the acceleration, and, upon cessation of acceleration, it would be moved forward by the spring, until it finally acted to close the detonator circuit. Since the time of the return stroke was dependent on the length of the piston travel, automatically variable arming time could be secured that would be controlled by the amount of explosive charge used in firing the shell. A considerable amount of experimental work was done on this device, but it was found that the difficulties in its construction made it impractical. It was expected, for instance, that the effects of temperature upon the viscosity of the fluid, one of the silicones, would be largely canceled out because of the double action of the piston; that is, that temperature effect on the down stroke and on the reverse stroke would be equal. This was found not to be the case because the downward

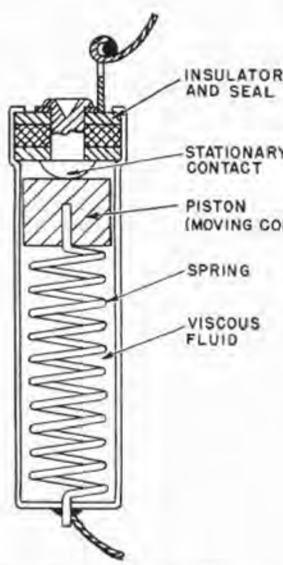


FIGURE 39. Diagram of dashpot arming device. This device gives longer arming times with larger values of setback.

stroke was extremely rapid, with the flow probably turbulent, while the reverse stroke was slow with laminar flow.

The method of making the electric connections to the T-132 detonator was another departure from the practice followed previously. Contact springs were completely eliminated. One of the leads of the detonator was grounded through the rotor driving mechanism, while the other lead acted both as a mechanical stop and

[redacted]

as the "live" contact. In this manner, the force of the rotor driving spring was employed to insure good contacts at both detonator leads. The details of the detonator rotor and the methods of assembling the detonator to the detonator rotor are described in reference 23. A photograph from this reference is shown in Figure 40.

The electronic assembly of the T-132 included a technique which, while not new in

FIGURE 40. Jig for forming and cutting detonator leads in mortar fuzes. At bottom of photograph are shown from left to right: detonator, detonator rotor, detonator rotor with detonator installed, bottom view of detonator rotor showing lower face of detonator.

general, was new in the case of proximity fuzes. It consisted of painting the resistors and condensers directly upon a ceramic supporting member. The antenna insulator was also constructed of ceramic material, and many of the oscillator components were also painted directly on it. The interconnecting leads and some of the plates of the capacitors consisted of silver plating on a surface of these ceramic members. In the original models of the mortar fuze built at NBS the electronic components were held between two thin Bakelite plates. This general design was copied by the Globe Union Company in their design of the first ceramic plates. The two plates can be seen in Figure 41.

From tests in the field and in the high-speed centrifuge it soon became apparent that the weight of the components and the potting compound above these plates was sufficient to break them when under setback. It was immediately suggested that it would be better to mount the ceramic plates vertically. Several different amplifier assemblies were tested, and it was found that a single rectangular plate could support all the necessary components with a great saving in space. The test terminals were mounted directly on one of the edges of this plate, thus eliminating the terminal block of the previous constructions. A cutaway view of the T-132 with the vertical plate amplifier is shown in Figure 42.

The antenna insulator was fastened to the metal shell of the fuze by soldering it to its silver-plated surfaces. In the case of the T-171 fuze (Figure 43), the ceramic antenna spacer was replaced by a mica-filled phenolic antenna block, which was molded directly onto the base member and which had around its forward section a metal ring, to which the shell of the fuze proper was fastened. This construction resulted in an extremely rigid assembly, and the later models of this fuze as well as of the T-132 successfully withstood the jolt test.

With the exception of the snap-out shaft described above, the arming systems of the T-171 and the T-132 were identical.

The overall dimensions of the T-132 and the T-171 were determined as follows. It was decided to make the mortar fuze fit the standard fuze well. The 2-in. diameter was determined by the availability of the Zenith generator which, at the time, was the smallest available. Many shapes of the nose section were tested in the NBS wind tunnel, and it appeared that the flat nose cap resulted in the greatest stability of flight. This cap was, therefore, the one used in the initial production.

When it became obvious that the flat cap resulted in too great a loss in range and there arose the possibility of using tail extensions to improve the ballistics, several caps with better

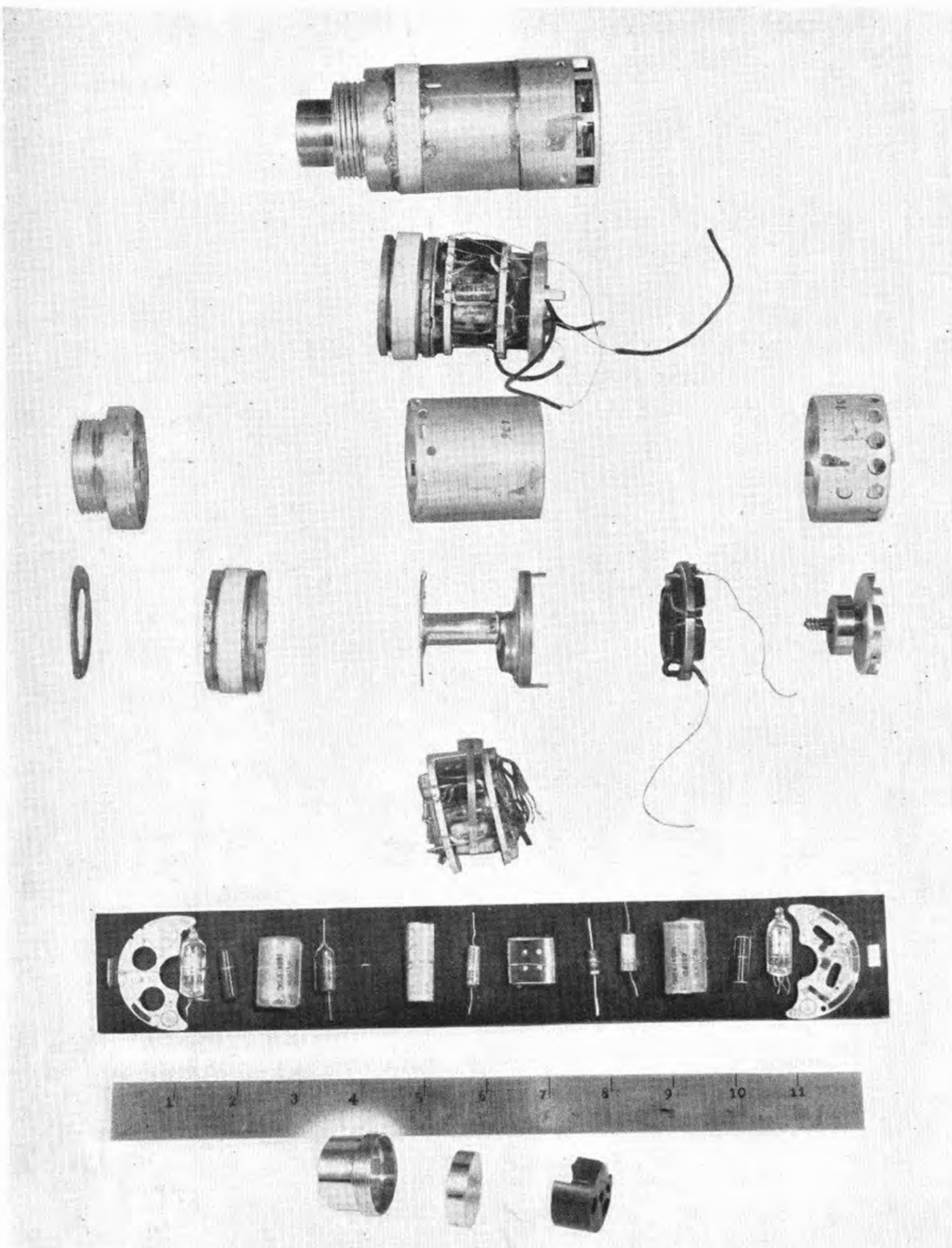


FIGURE 41. Assembly and principal components of T-132 fuze. Assembly shown uses "horizontal" ceramic plates which were replaced in later models of this fuze.

streamlining were designed. The modification adapted for the T-132 and the T-171 was the 132A cap shown in Figure 43 and in Figure 6 of Chapter 1. Further increases in streamlining with the same turbine did not prove worth while.

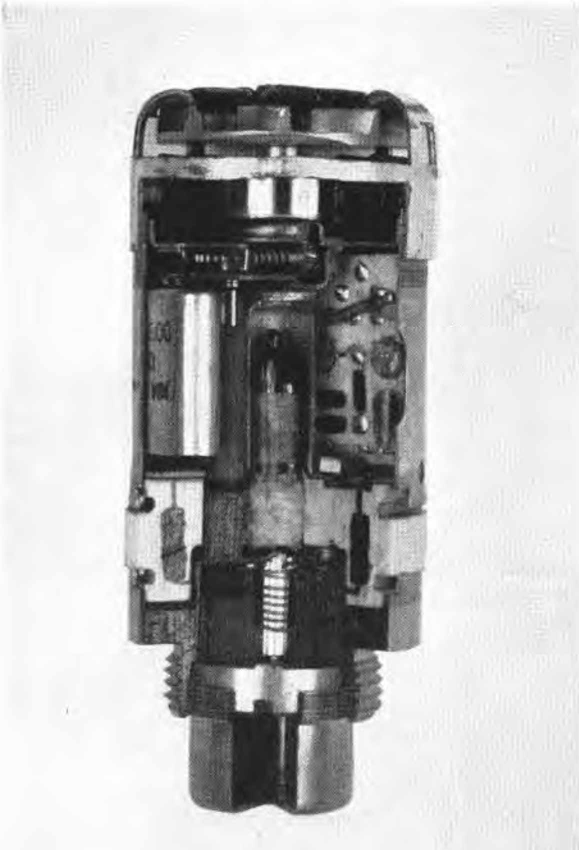


FIGURE 42. Cutaway of T-132 fuze. On right center of photograph may be seen vertically mounted amplifier used in later models of this fuze. See Figure 34 for identification of components.

MORTAR FUZE, T-172

A rather radical departure from the T-132 and T-171 mortar fuzes was the T-172 fuze developed by the University of Florida. In order to get a more forward-looking angle of sensitivity of the antenna, a loop antenna was employed. This meant that the power supply and most of the electronic components of the fuze did not have to be isolated electrically from the body of the shell. It also indicated the desirability of locating the generator in the base of the fuze so as to permit the use of a plastic cap at the base of the loop. A central air duct was provided for the intake, and a series of round holes near the base of the fuze provided the exhaust. The fuze is shown in Figure 44. By making an extremely compact electronic assembly, the overall dimensions of the fuze exclusive of the loop were equal to those of the T-132. Placing the power supply in the base of the fuze permitted the direct coupling of the

FIGURE 43. T-171 trench mortar fuze.

generator shaft to the arming mechanism. The gear train was, therefore, located adjacent to the detonator, and the whole assembly of the gear train and detonator was made to revolve into the armed position at the completion of 400 yd of air travel.

One of the problems encountered in the development of this fuze was the difficulty of obtaining sufficient power from the turbine at the lowest air velocities. The best shapes of the intake were such as to increase the drag of the fuze. Compromise solutions had to be employed.[61, 72]

FIGURE 44. T-172 mortar fuze.

A special generator was designed for the T-172 (see Figure 45)[72] by the Zenith Corporation. It was similar to their six-pole T-50 and T-51 generator but used only three coils. By an ingenious method of assembly of the stator, the coils were wound directly on the pole piece assemblies. Another advantage of the design was the fact that the pole pieces were supported against setback by a brass ring. This generator was equipped with precision ball bearings. The first models of the Zenith T-172 exhibited several weaknesses in the method of supporting the assembled generator, but these were soon rectified.

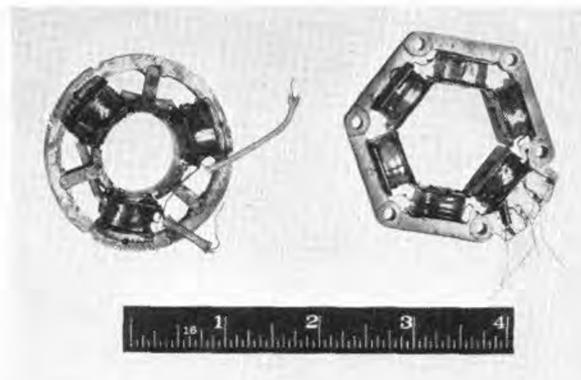


FIGURE 45. Three-coil generator for T-172 mortar fuze.

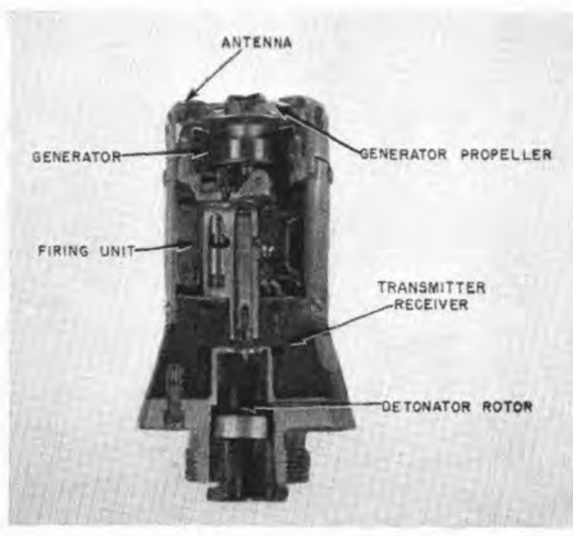


FIGURE 46. Cutaway of T-2005 rocket fuze.

The end of hostilities prevented any large-scale production of the T-172.

In all three of the mortar fuzes described

above, a $\frac{5}{16}$-in. thick brass plate was used as the interrupter below the electric detonator.

ROCKET FUZE, T-2005

The success attained with the mortar fuzes and the advisability of designing a much more universal rocket fuze than the T-30 and the T-2004 led to the development of the T-2005.[78] Since this fuze was intended primarily for the Navy/California Institute of Technology rockets, its physical outlines were designed accordingly. As can be seen in Figure 46, the base section extends very little into the fuze well, and the main body of the fuze is mounted forward of the projectile. The general design is very similar to that of the T-171. The antenna insulator is made broader and heavier, both to give increased strength and to result in better streamlining.

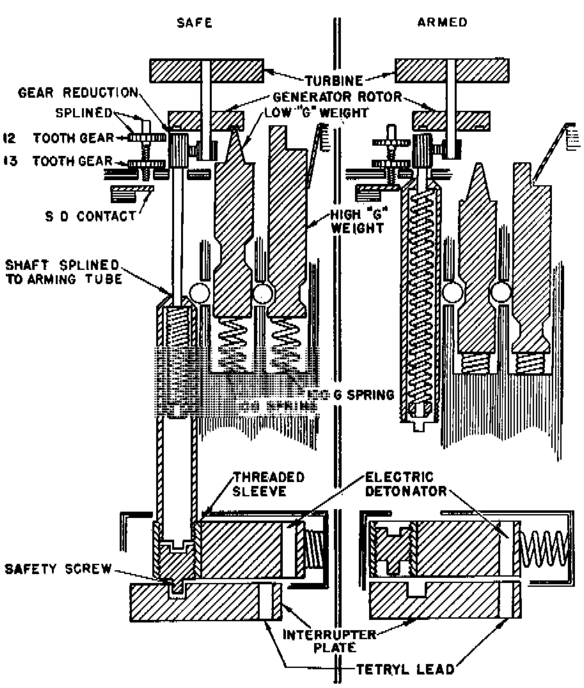


FIGURE 47. Schematic arrangement of arming mechanism for T-2005 fuze. Arrangement in safe or unarmed position is shown on left, in armed position on the right.

The generator power supply is practically identical with that of the mortar fuzes. The pitch of the turbine blades was, of course, reduced to result in a speed of 20,000 to 80,000 rpm for projectile speeds of 800 to 3,200 fps. It was decided to use precision ball bearings for this fuze, since problems of setback support and procurement were much simpler than in the corresponding cases for the mortar fuze.

The arming system of the fuze, however, requires considerable explanation. It was considered desirable that the use of any arming wires or manually removable pins should be unnecessary, although their use should be provided for as optional. The fuze should be capable of being mounted on a projectile below the wing of a pursuit ship without any danger of being armed by the airstream. This naturally required that the rotating system of the fuze be held from turning until after the firing of the rocket. The arming system was to operate when subjected to an acceleration greater than $10g$ and perhaps as high as several thousand g. This fuze should not arm in less than 300 yd under any condition. If the burning of the rocket continues beyond 300 yd, the fuze should not arm until after the completion of burning. An SD element had to be provided that would explode the rocket after approximately 6,000 ft of air travel. This SD feature had to be optional, to be inserted or removed in the field. The fuze was to be capable of passing the jolt test. A simplified drawing of the main components of the arming system is shown in Figure 47.

A brief description follows: A weight supported by a spring and provided with a pin in its forward end acts to lock the turbine in the fixed position. This weight is normally free to move back and forth. When the fuze is fired in the normal manner, this weight moves back, permitting the air to drive the turbine, the shaft of which is coupled to a gear train that lifts an arming rod in a manner somewhat similar to that in the T-132. This gear train also performs another function, that of locking down the setback weight at the end of 100 turns of the turbine. This means that if the 10-g acceleration is maintained for a distance of roughly 100 yd, the turbine is permanently released and can continue to operate and then arm the fuze at the end of 300 yd. For high-g rockets, and possibly artillery shells, on which this fuze may be used, another weight was provided that was retained in its normal position

[redacted]

by a 100-g spring. This high-g weight was interlocked with the low-g weight described above in such a manner that if the fuze experienced an acceleration of over $100g$, the low-g weight would move back first, permitting the high-g weight to move and lock it in the lower position. This action is identical with that of all the other double-element setback devices mentioned previously in this report.

The 300-yd minimum arming distance is not affected by this action, so that in all cases the T-2005 fuze cannot arm until a safe distance away from the launcher. For those cases in which the rocket burning continues beyond the 300-yd mark, a mercury switch is provided which keeps the detonator circuit open until the forward acceleration ceases. An electric RC increases the safe air travel still further.

Since no double-element setback release was provided directly in the detonator rotor, the danger of its arming due to the breakage of the antenna insulator still existed as it did in the case of the original mortar fuzes. Because of the low values of acceleration, a small double-element safety was not practicable in the detonator rotor. A different mechanism was, therefore, evolved. The arming shaft, instead of serving merely as a pin to lock the detonator in position, was modified so as to rotate as it was withdrawn. This rotation was communicated to a local arming screw, which also served to lock the detonator rotor in the safe position; that is, the arming shaft was used both as a lock and as a screw driver. If, while the fuze was in the safe condition, the antenna insulator was broken and the arming shaft fully withdrawn, the locking screw would still remain in its safe condition, and the detonator would not move.

The SD was accomplished by a rather simple form of differential screw. Two small gears of 12 and 13 teeth were arranged to mesh with one of the pinions of the regular arming gear train. These two gears were mounted on a fine screw used as their shaft. One of the gears was coupled to the screw by means of a spline, and the other was threaded onto it. In this manner, as the two gears revolved slowly at slightly different speeds because of their one-tooth difference, the screw was slowly moved downward so as to "ground" the firing circuit at the end of several thousand feet of air travel. If the use of SD was not desired, it was possible to disengage the small gears by the simple removal of a small screw projecting through the case. The whole SD assembly was mounted on a small spring, which normally kept it out of engagement with the driving pinion.

4.3.5 Miscellaneous Experimental Fuzes

As mentioned at the beginning of this chapter, many fuzes were considered and experimented with that never saw production. Of particular interest were the T-40 and T-43 fuzes, familiarly known as Katrinka, which were intended for operation on very large bombs. The intention was to use the fin structure as part of the antenna loop and to make use of the bomb body by shunt excitation.[55] The fuze itself was to be mounted in a cylinder approximately 6 in. in diameter and 12 in. long placed inside the fin structure. The energy was to be derived from a battery that was to be either very well insulated so as to maintain its ground temperature for long periods or that was to be heated electrically by the plane's power supply.[77]

A small turbine was designed to energize the arming mechanism. A feature of this mechanism of particular interest was the variable arming that could be controlled from the plane. The arming system contained a differential gear, one side of which was driven by the turbine, while the other side was connected by means of a flexible cable to a control in the plane. The output of the differential gear controlled the position of the detonator. The flexible cable was to serve both for setting the fuze and for releasing the arming system in the manner similar to that of an arming wire. Drawings of the mechanical system were made and some of the components were actually built, but the project was abandoned before a working fuze was constructed. Other fuzes, particularly the T-51, appeared capable of fulfilling the application for which the T-40 and T-43 were intended.

Another experimental fuze was intended specifically for air-to-air bombing, particularly for

[redacted]

use with toss-bombing equipment (cf. Division 4, Volume 2, STR). This fuze was given the designation P-4 771B by Bell Telephone Laboratories where the development[76] was carried out. A particular requirement for this fuze was ability to operate satisfactorily at lower airspeeds at high altitudes. This resulted in a larger turbine system for the power-supply generator. Air was directed to the turbine by scoop or air duct around the periphery of the fuze. A photograph of the fuze is shown in Figure 48. Several models were built which operate satisfactorily against ground targets. No air-to-air tests were conducted and the project was abandoned because of the lower priority given later in World War II to air-to-air weapons.

FIGURE 48. Experimental model of generator-powered fuze for air-to-air bombing.

4.4 THE MOUNTING OF FUZES INTO MISSILES

Since the vehicle carrying a radio proximity fuze often acts as an antenna and in all cases has an effect on the radiation, the method of fastening the fuze to the projectile is more critical than with contact fuzes.

For contact fuzes two practices are more or less standard. If the fuze is shipped as part of the complete round, it is permanently fastened in place, usually by staking. Where the fuze is inserted into the vehicle in the field, this is usually done without any special tools, and hand tightening is considered sufficient. No lock washers of any kind are employed.

In the case of proximity fuzes this procedure is not tolerable. Loose mounting results in both mechanical and electric noise. Extensive studies were carried out[6] to determine the best methods of mounting fuzes in missiles to reduce both mechanical vibration and poor electric contact.

The M-8 rocket and the mortar fuzes were designed to be wrench tightened. The bomb fuzes were to be assembled in the field, preferably after the bombs were in their racks. To insure good electric connections, lock washers were specified. Special wrenches were provided for all the fuzes. Lugs were provided on the fuze housing (cf. Figures 16, 20, and 26) to provide anchor points for the wrenches.

The using Services soon complained that the Shakeproof lock washers supplied for the T-50 fuzes did not permit easy defuzing. Also, there was noted on the part of the field personnel a tendency to use the dipoles of the T-51 and the T-82 as handles in tightening or loosening the fuze in its well. Accordingly, a more suitable washer was developed. It was manufactured by

the Shakeproof Company and in its outline was a duplicate of their external-toothed lock washer. Instead of twisting the teeth, however, they were bent alternately back and forward. This resulted in a spring washer that provided considerable friction between the bomb and the fuze without a positive lock action. It also permitted the operator greater leeway in the angular setting of the fuze with respect to the bomb for greater convenience in the use of the arming wires. Photographs of both the spring

FIGURE 49. Washers used for mounting fuzes in bombs. Lock washer is shown on the left, nonlocking spring washer on the right.

washer and lock washer are shown in Figure 49.

It was found that the dipoles of the T-51 and T-82 were sufficiently strong to be used as handles, when this spring washer was employed.

4.5 SPEED REGULATION

Very little has been said so far about the desirability or practicability of automatic speed regulation for the various windmills and turbines used in the Division 4 fuzes.

There are several reasons why a constant generator speed is desirable.

1. If the generator could be operated at constant speed at the various velocities of the vehicle, electric voltage regulation would not be necessary.

2. The bearing life could be greatly prolonged.

3. The vibrational forces could be maintained at a minimum, thus increasing the amount of permissible unbalance in the rotating systems.

4. The strength requirements of the rotating system could be eased, permitting a greater choice of materials for the construction of the turbine and the rotor assembly.

5. It would permit the standardization of the drive for the fuzes required for different applications.

6. By maintaining a reasonably constant speed, the arming system would be in effect a time mechanism rather than an air-travel mechanism. This would be of particular advantage because most of the ballistic tables of the Services are expressed in units of time.

In contrast to these obvious advantages there is the disadvantage of greater complexity introduced by the regulating mechanism. This is particularly serious, since it is very important that the fuzes be capable of withstanding extreme conditions of temperature and acceleration.

It is, of course, obvious that a great many mechanisms can be designed to control the speed of an air turbine. Yet, at the time of the work, no speed control system was known that did not require the addition of some moving parts and that would depend merely on the aerodynamics involved. The matter was discussed without success with representatives of many companies, who normally engage in the construction of pumps and turbine. In the summer of 1945, the Douglas Aircraft Company of California and the University of California engaged in research on the shape of nozzles in order to obtain speed regulation for the T-172 fuzes. (This work was sponsored by the Transitions Office of NDRC.) Their report[60] concludes that some regulation is possible by designing the nozzle in such a way as to obtain sonic speeds through the throat. This will not give perfect speed regulation since the pressure in the throat is roughly proportional to the pressure at the nose of the projectile, and, therefore, the total mass of the air moving through the fuze will vary with the velocity. Tests at the National Bureau of Standards on a similar mechanism of controlling airflow did not give encouraging results. Nevertheless, some rather simple mechanisms for controlling the speed of propellers were tested, and some bomb fuzes equipped with these were actually dropped. Perhaps the simplest of these, shown in Figure 50, was the mounting of the windmill

on its hub so that it had some axial freedom. A spring inside the propeller hub was compressed when the windmill was driven back against the flat nose of the fuze. This effectively decreased the airflow and decreased the windmill speed. The speed regulation, while not perfect, was quite stable.[1,2] The disadvantage of the scheme lay in the fact that the windmill had to be somewhat free upon its shaft, resulting in a relatively large amount of vibration and preventing the possibility of good balancing.

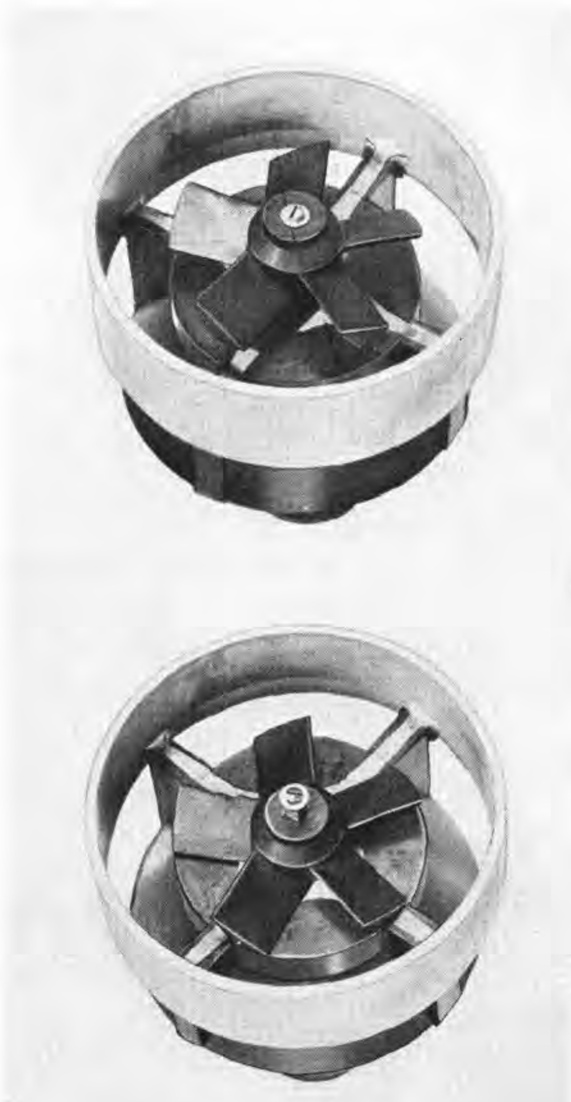


FIGURE 50. Windmill for speed regulation. Normal position of windmill on its shaft (*top*); windmill depressed by air pressure (*bottom*).

The use of flexible blades in the turbines has already been mentioned in connection with the T-82. Another suggestion to use centrifugal regulation came from Zenith and was investigated by the University of California.[60]

In both the above schemes flexible members are employed. These are necessarily located in the airstream. Consequently, vibrations of high frequency and high amplitude are set up in the flexible members, resulting in rapid fatigue. Another objection to the flexible blade schemes is the difficulty of maintaining accurate dynamic balance at all speeds.

The overall solution of the high-speed problem was the use of well-balanced rotating systems, materials of sufficient strength, and the proper bearings to permit the rotational system to withstand high speeds without ill effects. This method of attack is satisfactory as long as the maximum velocity range of the projectile is not greater than approximately 4 to 1. As the range of velocity of the projectiles equipped with similar fuzes is increased much beyond that, speed regulation will undoubtedly have to be employed.

1.6 DYNAMIC BALANCING

Although the problem of balancing the rotating system of a fuze may appear to be a production problem, not particularly related to fuze development, appreciable work was done on the subject by Division 4. While commercial equipment for dynamic balancing was available during World War II, such equipment was not available on the scale necessary for the production envisioned. The commercial equipment was both complicated and expensive and could not be duplicated by the fuze manufacturers themselves. As the fuze program advanced, it became more and more evident that the mechanical design of generator-powered fuzes could be simpler and fuzes would be more reliable if the rotating systems were dynamically balanced. This required that suitable equipment be available for doing the balancing in production.

Soon after the T-50 program was started, it was found that some units were much noisier than others due to the large amplitudes of vibrations caused by the rotating systems. A process of selection was then applied to the windmills before their assembly. A simple unbalance tester was built, consisting of a flexibly mounted fixture coupled to a crystal pickup,

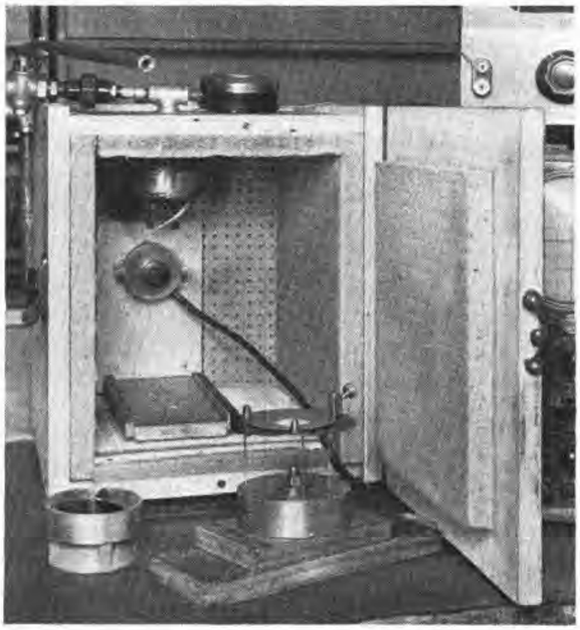


FIGURE 51. Equipment for dynamic balancing of vanes of T-50 type fuzes.

which was fed into an amplifier, the output of which was read on a suitable meter. It was soon found that it was difficult to distinguish between the rotational vibration of the fuze head and the noise due to the rather crude ball bearings employed. A rather sharply tuned filter was then introduced into the amplifier, and the speed of the windmill was manually adjusted so that the rotational vibration was kept at the frequency at the center of the amplifier peak. In this way, badly unbalanced windmills were isolated from the rest.

It was a simple matter to go from this step to a stroboscope, which was triggered by the unbalance voltage and indicated the position of unbalance. The circuit was so arranged that, as the instantaneous unbalance voltage passed through zero, it triggered a thyratron which, in turn, flashed the stroboscope light. The windmill appears to stand still under this light. By taking a vane and deliberately unbalancing it, the equipment can be easily calibrated. A photograph of this equipment is shown in Figure 51. In this method of balancing no effort was made to achieve true dynamic balance, but since the windmill can be considered to be a nearly flat disk mounted at the front end of a rather large mass hinged at its base, the removal of static unbalance in the vane reduces the vibration of the large mass to a very low figure. In the T-50 production no effort was made to balance the rotor of the generator.

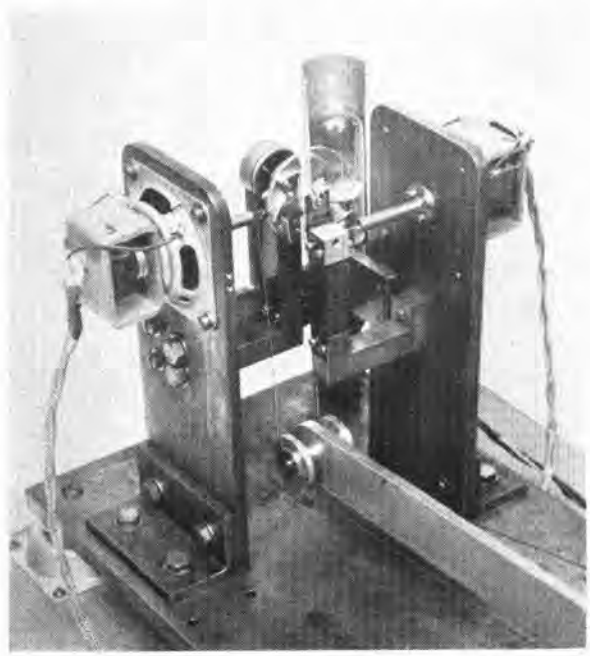


FIGURE 52. Close-up view of dynamic balancing machine for rotating systems of mortar fuzes.

The equipment described above was employed on a large scale by the manufacturers engaged in the T-50 fuze program.

True dynamic balancing was a requisite in the construction of the mortar fuzes, and the machines of various manufacturers were inspected for suitability. Since the original intention in this program was to use ball bearings, it was important that the dynamic balancing equipment should be able to distinguish between ball bearing noise and rotational unbalance.

It was known that the Westinghouse Com-

pany had developed a system of "Micro-Dynetric" balancing capable of accomplishing this. A group of NBS and Bowen engineers visited the Baltimore plant of this company and witnessed the operation of the only model of that machine in existence. The machine appeared suitable for the purpose, and orders were placed by Bowen, Globe Union, and others for the procurement of this equipment. It became immediately apparent that its production schedule was very much slower than required for the fuze program, and NBS undertook to design a simple and easily produced balancing machine for the project.[9] The machine, photographs of which are shown in Figures 52 and 53, is similar in operation to the standard machines of the Gisholt Company and others except for considerable simplification. The rotor drive consists of a synchronous motor so as to maintain a constant speed. The pickups are two standard 2-in. permanent magnet dynamic speakers. The amplifier is very sharply peaked at approximately 95 c, and the rotor to be balanced is belt driven at 95 rps. The output of the amplifier is fed into a vacuum-tube voltmeter by means of which the magnitude of unbalance can be determined. The output voltage also triggers a stroboscope which locates the position of unbalance. In a later model automatic volume control was employed so that no manual changes of amplifier gain had to be used for a wide range of rotor unbalance. The removal of metal was done by hand.

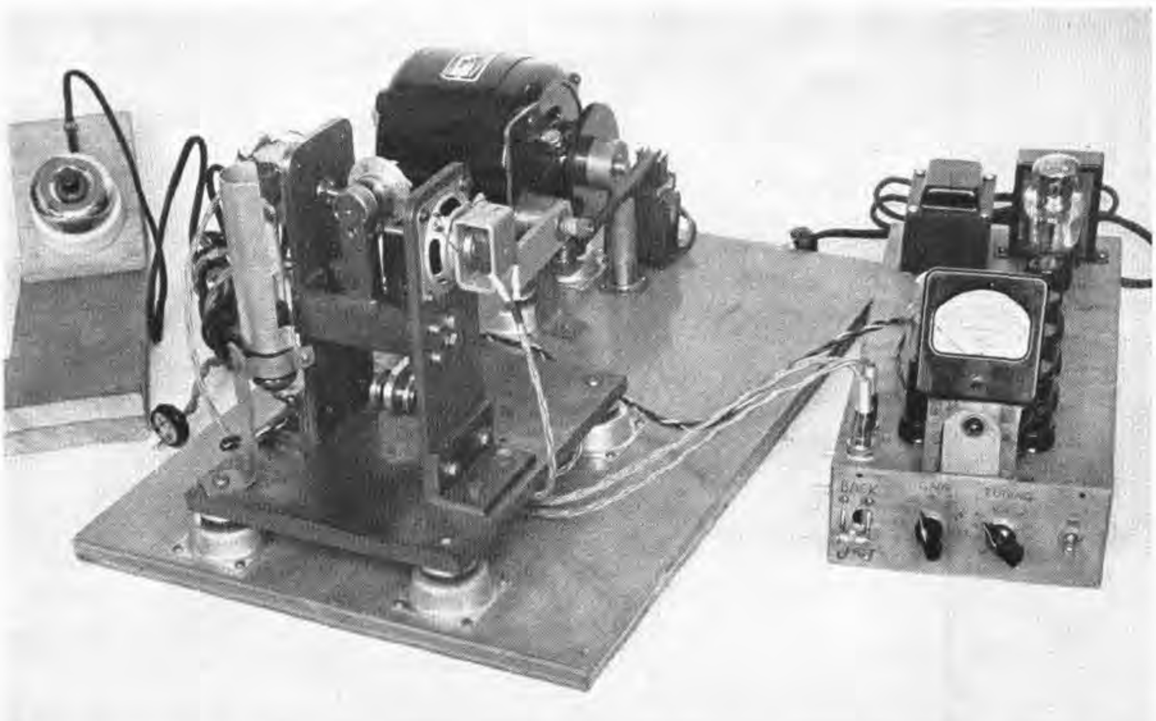


FIGURE 53. Dynamic balancing machine shown in Figure 52 and accessory equipment.

Modifications in this equipment were made by Raymond Engineering,[57] Zenith Corporation,[72] and the Bowen Company,[46] for the mortar fuze production program. Unbalances of the order of 0.05 g-in. could be detected readily and corrected.

True automatic balancing in the sense that the balancing machine either adds or removes mass in the proper places in the rotating assembly was, of course, considered, but the pressure of work and the termination of World War II forestalled any work on the several schemes suggested.

4.7 CHOICE OF PLASTICS FOR THE PROXIMITY FUZES

4.7.1 T-5 and T-50 Type Fuzes

One of the problems presented in the construction of the rocket and bomb proximity fuzes was that of determining and developing the proper plastic materials to be used in the nonmetallic portions of the fuze.

Some of the basic requirements for suitable plastics were high compression strength, high impact strength, dimensional stability, and good electrical properties at high frequencies. The electrical properties included low dielectric constant, low power factor, and high leakage resistance. The main problem, then, was the search for plastic materials with the above properties that were commercially available or could be produced from materials available in large quantities.

The principal plastic parts of the fuze were the insulator nosepiece, to be made of plastic material with good electrical properties combined with good mechanical properties, and the oscillator block, for which a plastic with good electrical properties was needed. Since the block was mounted on a steel plate, high mechanical strength was of secondary importance. On the other hand, the terminal plate that seals off the audio portion of the fuze requires high mechanical strength together with high d-c leakage resistance. The rectifier housing, the detonator rotor housing, and the detonator rotor all require a plastic material of high impact strength and good dimensional stability. For these pieces the electrical requirements are of secondary importance.

In the original choice of material for the nosepiece, the electrical requirements had to be subordinate to the mechanical requirements because of the particular mechanical design chosen. There was sufficient space between the antenna insert and the body of the fuze to cause the electric gradients to be low enough not to interfere seriously with the sensitivity of the unit. Because of this large space, the effects of humidity on the plastic were also of minor consideration. Moreover, the high surface polish of the molded plastic further reduced the effects of humidity by forming a good surface seal.

Dimensional stability, absence of cold flow, and high-temperature heat distortion were considered points of primary importance in the design of the nosepiece. Any looseness would be extremely objectionable when the fuze vibrated in operation. Electric noise, which would result, would produce a spurious signal, causing the fuze to malfunction. One of the methods used to fasten the nose to the main body of the fuze was the use of knurled steel inserts. The use of these knurled inserts precluded the use of most of the thermoplastic materials, not only because of cold flow, but also because the points on the knurling would cause stresses which, in turn, would produce crazing and so destroy the mechanical strength of the piece. When the nosepiece was further modified to include the holding of the nose to the base of the fuze by through screws, the large compressional forces under the screw heads were still a source of trouble because of crazing.

Tests of various thermoplastic materials, such as methyl methacrylate and styrene, for cold flow and crazing, showed that these methods were not satisfactory for use with the particular design involved. It was determined that mica-filled phenolic was the best available material. Various brands of low-loss mica-filled phenolic were tested for compression strength, creep, electric resistance, dielectric constant, and power factor. During these tests it was found that the effective impedance of the mica-filled phenolic available from the several different manufacturers varied by a factor of as much as 2 to 1, although all the material tested was submitted as conforming to the same set of specifications.

In the construction of the oscillator block for the first fuzes, the same material was used as in the nosepiece, because these fuzes (oscillator diode type [OD]) had a tuning condenser molded into the block. In order to maintain the constancy of tuning, extremely good dimensional stability was required along with freedom from effects of humidity. The dimensional stability was satisfied by the mica-filled phenolic chosen, and the freedom from effects of humidity was

obtained by finishing the surface of the plastic properly. For the more recent fuzes, in which the tuning condenser was eliminated, a styrene block was used because of its superior electrical characteristics and the ability of cement to form a better bond with the styrene. The block was anchored in place to a metal base plate, thus giving the sufficient mechanical strength.

In the terminal plate a linen-filled phenolic was used for its high mechanical strength in a thin sheet. In order to preserve high leakage resistance, this plate was boiled in wax to seal it against the effects of humidity. The main function of this terminal plate was to hold the components and potting material in the audio-frequency portion of the unit. The high leakage resistance was made necessary by the fact that one of the test leads was part of a circuit, the operation of which was affected by a leakage resistance of 100 megohms.

In the mechanical section of the fuze, which included the generator housing, the gear train housing, the rectifier housing, the detonator rotor housing, and the detonator rotor, a high-impact phenolic material was used. High impact strength and dimensional stability were the basic requirements. It was later found that the dimensional stability of the material was not sufficient to take care of the small tolerances required in the generator housing, and it was necessary to substitute a pressed metal housing. Some difficulty was also experienced with the detonator rotor. Consequently, the batches which did not maintain their tolerance because of poor molding were rejected.

4.7.2 T-51 Fuze

To modify the T-50 fuze so that the radiation pattern would appear directly in front of the fuze, it was necessary to use a transverse bar, or dipole. In order to conserve developing time and reduce as far as possible the need for designing new components for this fuze, it was decided to use as many parts of the original bomb fuze as possible. To get sufficient mechanical strength with this design and to keep the overall length of the fuze the same, it was necessary to mount the dipoles at a much lower point on the nosepiece; consequently, the field intensity or voltage gradient between the dipoles and the metal base of the fuze was much higher. Because of these high field intensities and because of the desire to obtain greatly increased sensitivities, it was necessary to obtain an insulating material with the best possible electrical characteristics. It was already known from previous experience with styrene and methyl methacrylate that the heat distortion point was too low and the material was subject to cold flow and crazing. However, because of the need for the superior electrical properties found only in styrene, a search for a suitable modified styrene was made and Monsanto's Styramic 18 was chosen initially. While its mechanical strength was lower to a considerable degree than that of the mica-filled phenolic, it was felt that it was still sufficient for the purpose. Later experience proved that it did not have quite the mechanical strength desired, and a modification of this material, Monsanto's Styramic 18A, was then used. This material has proved to be satisfactory in all respects.

Later in the development other material appeared on the market in quantities sufficient for production needs. One of the outstanding materials was Dow Q247, which had all the desirable mechanical properties of the Monsanto Styramic 18A as well as slightly better electrical properties.

4.7.3 T-171 and T-132 Fuzes

In the T-171 fuze for the 81-mm mortar shell, Dow Q247 was used. The higher radiation resistance of these missiles and the shorter electric leakage path (because of reduced size) made insulating properties of the plastic a prime consideration. At the beginning of this project mica-filled phenolics were tried, but the sensitivity of the unit was only marginal. In this type of fuze the plastic material had to support the weight of almost the entire fuze. The generator as well as most of the mechanical parts had been moved to the nose of the fuze to act as an antenna, and the plastic was used to mount the oscillator and act as an insulating spacer. Because of improved design of the in-

serts, the problem of cold flow and crazing no longer had its original importance. In the T-132 fuze no plastic material at all was used, the insulating material being a low-loss ceramic.

4.7.4 T-2005 Fuze

Because of its success in the T-51 bar-type fuze, the same plastic material, namely Styramic 18A, was used in a fuze designed for the Navy rockets. The design was somewhat similar to that of the mortar fuze. The generator was in the nose portion, and the oscillator was built in the leading edge of the plastic antenna insulator. If the development of this fuze had continued further, possibly a change to Dow Q247 would have been desirable, as this material has much higher flexural strength.

All the components molded of Styramic 18, Styramic 18A, or Dow Q247 used in the fuzes described above were quite thick and irregular compared with the usual piece commercially molded. Because of the poor heat conductivity common to all plastics and the thickness of the sections involved, it was necessary to anneal the pieces in order to obtain a strain-free product. This was accomplished by placing each complete piece in a tank of hot water and moving it into successively cooler tanks as the cooling took place. The gradual cooling effect thus obtained removed internal strains and resulted in the production of uniformly strong pieces. In order to obtain moldings of sufficient strength and density, it was necessary to heat the plastic almost to the burning point. The molds themselves were run warmer than in usual commercial practice. This was done in order to prevent too thin a case hardening. All the inserts, dipoles, and nose bearings had to be preheated in order to prevent too sudden cooling as the warm plastic reached those points in the mold.

4.7.5 Cements

It was desirable in all cases to eliminate as far as possible the electric noise produced by mechanical vibration; therefore, the r-f components used in the proximity fuze had to be so firmly anchored together that they could not be loosened by vibration, temperature variation during storage, or any shock experienced by the bombs or rockets.

In order to anchor the different components in place successfully, it was necessary to use an adhesive possessing certain qualities: low electric losses and the elimination of strains and lift due to the difference in coefficient of expansion between the cement and the component to which it would be attached. The most frequently encountered base material on which the cement was to be used was mica-filled phenolic.

The styrene solutions which were available during the first stages of production presented a major disadvantage in their inability to release solvents readily. Under infrared heaters 24 hours were generally required. If the solvents were still present, the maximum adhesive strength could not be obtained, and the solvents themselves produced electric loss. When these styrene solutions did finally become completely free of solvents, they became so brittle that they would lift upon the slightest shock. The latter problem was solved by sand-blasting of the base material and, consequently, the roughened surface of the mica-filled phenolic blocks held the cement mechanically. However, the roughened surface, in opening the pores of the material, allowed moisture to be absorbed much more readily than with the original smooth hard surface. Subsequently, greater electric loss resulted. Tests were then made using a phenolic sirup with powdered mica added, which was developed by Globe Union, in order to obtain a final coefficient of expansion of the polymerized mica-filled material equivalent to that of the mica-filled phenolic block.

Another approach to the problem was made by using a mixture of styrene, polymer, and monomer. In this mixture no solvents were required to be released, since the monomer polymerized to a solid. It was necessary to add polymer to the monomer for two reasons: (1) it increased the viscosity of the solution to the point where it would stay in place, and (2) it would decrease the shrinkage on polymerizing

by the amount of polymer in the solution. When modified styrene compounds were used for molding the electric sections of the bar-type fuze, the styrene adhesive worked especially well. The adhesive had the same coefficient of expansion as the modified styrene blocks themselves; furthermore, the solvent used formed one uniform material. However, the inability of the styrene to release solvents readily caused the solvent to penetrate the block itself. The solvent-release problem was thus even more serious than it had been with the use of mica-filled phenolic blocks.

The next advance in the solution of the solvent-release problem was the substitution of plasticized vinyl carbazole, produced by General Aniline and Film Corporation, for the styrene type of adhesive. The solvent release time was reduced from about 24 to about 4 hours. This material had almost as good electrical properties as the styrene and satisfactory mechanical strength. Moreover, because it dissolved in the modified styrene base, its coefficient of expansion was not important.

Dichlorostyrene polymer monomer mixtures were also found to be satisfactory because of the compatibility in their use with the styrene block. One of their important advantages was the capacity to form an extremely hard glass-like material, with superior electrical properties, in about 2 hours. There was, then, no need for the release of any solvents. One of the disadvantages of the mixtures was the tendency for large forces to be set up upon shrinking in polymerizing. This difficulty was eliminated by proper plasticizing.

4.7.6 Potting

In a further effort to protect the electric components against the effects of temperature and humidity and to prevent the production of electric noise in the amplifier portion of the units, potting material was poured in place.

The material used had to possess certain characteristics. It had to have a reasonable amount of elasticity over an extremely wide temperature range, low electric losses, dimensional stability, ease of handling, short polymerization time, and nontoxic qualities. The initial material tried was wax. This was unsatisfactory because of its low melting point and its tendency to sweat at high temperatures. In order to allow the wax to flow around the components readily, a high pouring temperature was necessary. Consequently, there was a tendency for the electrical characteristics of some of the components being potted to be altered. At low temperatures the forces produced by shrinkage were actually sufficient to fracture some of the glass components.

Because of the trouble encountered with wax, various addition agents were tried. Two different mixtures were finally used. One, developed by Zenith Radio Corporation, consisted of 80 per cent microcrystalline wax and 20 per cent polyisobutylene, molecular weight 100,000. This material was used to hold the oscillator tube solidly in its tube well. This mixture was not too brittle at −40 C and did not flow or sweat materially at +60 C.

Another material was a mixture of 20 per cent ethyl cellulose, 20 per cent beeswax, and 60 per cent ceresin. This material did not have electrical properties quite so good as the previous mixture but was much stronger and had good temperature characteristics. It was found useful in the centrifugal potting of the generator stators in the T-171 fuze.

The material used largely throughout production was polymerized tung oil. This material was not entirely satisfactory. It could be poured into the cavities at room temperature and would jell in about a half hour. On jelling, it became a firm rubberlike mass similar to art gum. It had sufficient elasticity to withstand shock, and it was firm enough to hold the components in place. It was also sufficiently friable, so that it could be broken up with a knife for inspection or repair of the units. This material was thermosetting. Once set, it would not melt at any temperature, and the shrinkage was almost nil.

The polymerized tung oil, however, had rather poor electrical characteristics and was corrosive toward some of the metallic parts. Because of this, the electric components were usually coated with a thin coat of wax before potting. The speed with which the tung oil set

up depended to a certain extent on the amount of moisture present in it. By eliminating this moisture, the tung oil set up with much greater rapidity. The main advantage of eliminating the water from the tung oil was the increase in the d-c leakage resistance by a factor of 20 and the decrease in the power factor by a large amount. The dielectric constant was also reduced slightly.

Because of the need for a material with better electrical and mechanical properties, investigations were conducted for the development of insoluble soaps, such as Glidden PT1 and PT2, that could be poured into a unit in the liquid state. Saponification would thus occur in situ. When these soaps were substituted for tung oil, the incidence of certain types of rejects in production was changed from a normal 11 to 1 per cent. This material, however, had disadvantages. Its viscosity, which was higher than that of tung oil, somewhat hindered pouring. Its water resistance was not so good as that of tung oil, however, because the material was in a closed space. This had no ill effects on the operation or storage of the units. Also, the material did not have as high a mechanical strength as tung oil although it was found adequate for the purpose.

Because both of the above materials left something to be desired both from the electrical and the mechanical standpoint, work was done on the use of styrene co-polymers; Dow Q344 and Dow Q349 are probably the samples of the best available material of this kind. All the electrical and mechanical properties of the final set of these materials were completely satisfactory. The initial viscosity made them somewhat difficult to handle. Furthermore, the surface had to be sealed from the air to eliminate stickiness as air hindered the surface polymerization. These materials were used by the Wurlitzer Company for potting the oscillator components of the T-171.

4.7.7 Solder Flux

In the examination of a number of units over a period of time, units which were maintained especially for aging tests, it was found that some of the electric measurements in some of them were subject to a constant drift. When these units were opened and examined, corrosion was discovered around some of the soldered joints. At first this corrosion was thought to be due to the corrosive action of the tung oil potting material, until it was realized that the soldered joints were protected from the tung oil by a thin wax filament. This corrosion was then subjected to a chemical analysis and found to be a metal resinate. The resin which formed this resinate could have come only from the rosin in the solder flux.

Because of the almost impossible task of removing all of the flux from the finished soldered joint, it was desirable to investigate other fluxes which were thought to be less corrosive. The corrosion was produced by the absorbed oxygen, as the soldered joints were completely sealed by wax and tung oil from the air. In order to correct this situation, several other materials were examined as to their suitability for solder flux. One of the materials examined is known as polypale rosin, which is a rosin dimer. This material absorbs only half as much oxygen as is absorbed by ordinary rosin, and the corrosive effects are cut down proportionally. Upon testing, it was found that polypale rosin was also considerably superior to ordinary rosins as a flux because of its superior wetting qualities. This material has been used in the fuze production with excellent results.

[redacted]

Chapter 5

CATALOGUE OF FUZE TYPES[a]

5.1 INTRODUCTION

5.1.1 General Remarks

IN THE PRECEDING CHAPTERS of this volume, there were discussed the general military requirements of proximity fuzes, the basic theory of operation of radio proximity fuzes, and the fundamental principles of design of the important parts. The requirements of ideal fuzes were defined, and the limitations that are imposed by fundamental considerations were discussed. It was made clear that a combination of fundamental and practical factors made it necessary to design different fuzes for different purposes. It was shown that the design of a fuze was affected by complex problems of availability of components and by the need to make use of facilities and subassemblies provided by the development and production of fuzes of earlier design. Before launching upon a discussion of the manifold problems of producing the fuzes in large quantity and testing them in the laboratory and in the field, it is desirable to present a description of the various fuzes that were produced. It is the purpose of this chapter to provide such a description. Furthermore, at the expense of some repetition, the chapter may be read separately from the rest of volume, without undue loss of meaning although frequent reference is made to figures elsewhere in the other chapters.

The description that is given in this chapter is intended to provide for each fuze (1) a statement of the principal applications for which the fuze was designed and the limits, so far as known, within which satisfactory performance may be expected, (2) performance characteristics under typical conditions, (3) engineering data that are useful in the estimation of performance under certain conditions which are not covered herein, (4) miscellaneous data on important characteristics that distinguish one fuze from another, and (5) summary data charts for each fuze. For a full understanding of the terms used in the development of items (3) and (4) above, some reference to other chapters may be desirable. Such references are indicated in the following presentation.

Sources of Data and Acknowledgments. The scope of the chapter, as outlined above, is somewhat broader than is demanded by the logical development of this report. Information is presented that demands substantiation in subsequent chapters. This anticipation of results has the advantage that it permits the orderly presentation, in a single chapter, of the essential characteristics and limitations of each fuze. Enough has been said in preceding chapters so that the data in this chapter can be clearly understood. Enough will be given in following chapters to show the variations to which these data are subject. The discussion of variations and difficulties of production, and of testing in the laboratory and in the field, can be understood more readily with reference to the average properties of the fuzes as actually produced.

An effort has been made to select data that are representative of the bulk of production fuzes. Available data on experimental fuzes are also included in so far as possible.

It is important to note that many of the data given in this chapter are *average values,* or "best estimates." The characteristics of individual fuzes differ more or less from the average. A full account of the individual variations would lead to undesirable complications in this chapter. Discussions concerning the occurrence of individual variations and the reliability of the estimates are taken up in other chapters of this report.

It is appropriate at this point to acknowledge the courtesy of the Ordnance Department and the Signal Corps in providing much valuable information on the performance of production model fuzes in acceptance tests. Much of the

[a] This chapter was prepared by Thomas N. White, Jr., with the assistance of Rachel Vorkink, Paul F. Bartunek, Alan L. Leiner, and Rosalind Schwartz, of the Ordnance Development Division of the National Bureau of Standards. Bartunek is now with the Physics Department at Lehigh University.

most useful and reliable information on fuze performance under standard conditions came from these sources. Acknowledgment is made to these sources and also to the Army Air Forces Proving Ground, Eglin Field, Florida, the Naval Ordnance Proving Ground, Dahlgren, Virginia, and the Naval Ordnance Test Station, Inyokern, California, for special information on certain important experimental and service tests. In order to avoid complications it has been necessary to omit references to specific sources of data in this chapter. The reader can obtain a full appreciation of the value of the information obtained from military sources only by a study of other chapters, particularly Chapter 9 of this report.

Scope. The fuzes covered in this chapter are primarily those which reached large-scale production. Data on experimental fuzes are presented in Chapters 3, 4, and 9 and briefly in this chapter in Section 5.6.

Where the military requirements for performance are presented in this chapter they refer generally to production specifications rather than to the original requirements for the development project.

The technical specifications recommended by NDRC to the services for production fuzes are included in the bibliography.

5.1.2 Developmental Relations between Fuzes[b]

The first radio fuze developed was the longitudinally excited battery-powered T-5, designed for use on the 4.5-in. Army rocket M-8 in plane-to-plane firing. The T-6 was the same fuze provided with an extended arming time to make it suitable for ground-to-ground firing on the same rocket.

The first bomb fuzes that were produced in quantity were members of the T-50 group. These fuzes may be regarded as T-5 fuzes modified, as required, by the introduction of a windmill-driven generator and arming system and provided with a larger antenna and different oscillation frequencies. This antenna, in the form of a ring, led to the name ring-type fuze. In order to make the most of existing production facilities, the layout of the radio and audio circuits of the T-5 were maintained essentially intact. Two carrier frequencies, Brown for the T-50-E1 production model and White for the T-50-E4 production model, were found desirable in order to obtain satisfactory burst heights of bombs in the size range 100 to 1,000 lb. A number of experimental models were used, of which the most important were the T-50-E10 (Brown) and T-50-E3 (White). These were altered from time to time to try out changes in the radio and audio circuits and for other purposes. The production fuzes T-89, T-90, T-91, and T-92 were T-50 type fuzes improved in certain respects and modified to make them more suitable for certain types of bombing.

The rebuilding of the T-5 to provide a group of longitudinally excited bomb fuzes was recognized at the outset as an expedient, in that longitudinal excitation led to a considerable dependence of the burst height of the bomb upon the conditions of release (altitude and speed). This variation in performance was reduced somewhat through the use of a suitable amplifier characteristic, but the results represented some compromise with ideal requirements.

Accordingly, at the same time that the ring-type bomb fuzes were being developed, work was carried on (on a second priority basis) to develop a transversely excited (bar-type)[c] bomb fuze, the T-51. In order to take full advantage of the benefits of transverse excitation, considerable effort was made to obtain an amplifier characteristic that was relatively flat throughout the expected range of doppler frequencies. The performance characteristics of this fuze were markedly superior to those of the ring-type fuzes in certain important respects, particularly the relative independence of burst height on bomb size and release conditions, and

[b] The historical aspects of this account are overly simplified. For a much more detailed and accurate treatment, see reference 2 and the history of Division 4, NDRC.

[c] The terms ring- and bar-type were in use so extensively that they are now retained. The more fundamental terms, longitudinally and transversely excited, are used for fuzes that did not actually have rings or bars.

the greater burst heights attainable. Concessions to expediency in the matter of using the power supply and arming system developed for the ring-type fuzes made it possible for the T-51 to overtake the production rate of the T-50 group within a relatively short time.

A parallel but slower development, with minimal concessions to expediency, was that of the T-82 bar-type fuze. In this development particular emphasis was placed on the avoidance of disturbances in the radio- and audio-frequency systems arising from moving mechanical parts. In place of the windmill with its shaft running through the radio and audio block, an air duct was carried through the block to a base-mounted turbine. The T-82 fuze had also other advantageous features, but it had not been carried into full production at the close of World War II.

The ring-type bomb fuze, which, as mentioned above, had its origin in the fuze for the 4.5-in. Army rocket, was later modified for use on Navy aircraft rockets [AR] and high-velocity aircraft rockets [HVAR]. In this case the principal structural change was the introduction of an arming delay mechanism that prevented the arming of the fuze until a certain time after the burning of the rocket propellant. Two types of fuze were produced, both in the Brown carrier band. The T-2004 (Mk-172 Mod O), intended primarily for plane-to-ground (or water) firing with the 5.0-in. AR rocket, was in production at a relatively high rate at the close of World War II. The T-30 (Mk-171 Mod O) for plane-to-plane firing with the HVAR, was not so urgently needed and was not carried into full production.

Certain important developmental relationships are apparent in the structure of the group of rocket and bomb fuzes discussed above. Another group of fuzes, the so-called "miniature" fuzes, also shows certain close relationships among the members of the group. This group of fuzes was developed later, and considerable use was made of the information obtained during the development of the larger fuzes, although the structural relationships are not so apparent. The most advanced member of the miniature group was the longitudinally excited T-132 fuze for trench-mortar shells. One outstanding characteristic of this fuze, which was rapidly approaching the production stage at the close of World War II, was the use of circuit connections made by painting or spraying material through a template onto a ceramic block. Other members of the miniature group that were developed to a more or less advanced stage were the T-171 mortar shell fuze (incorporating standard electric components), the T-172 mortar shell fuze with a loop antenna, and the T-2005 general-purpose [GP] rocket fuze.

5.1.3 Performance Terminology

Certain important terms used to describe fuze performance require definitions. These are:

Proper Function. [Abbrevation: proper or P.] A fuze function attributable to normal interaction between the fuze and target.

Random Function. A spontaneous fuze function, or one not attributable to interaction between the fuze and the target. In Chapter 9, the random functions are called either "early" or "middle" functions for reasons that are there made clear. For the purposes of this chapter, there is little need for such a distinction and the term random function, which has been used extensively in the theaters of operation, is applied.

Sympathetic Function. The functioning of a fuze caused by the burst of a neighboring variable-time [VT] fuzed projectile (e.g., in salvo or train releases). Sympathetic functions may, under certain conditions, be caused by either random or proper functions, and in such cases are called sympathetic random or sympathetic proper functions, respectively.

Radius of Action [*ROA*]. A measure of the proximity to an airplane, or like target, within which reasonably reliable functioning of a VT fuze can be expected. The ROA is usually defined as the radius of a cylinder, with axis parallel to the trajectories, within which a specified percentage of proper functions should occur.

Afterburning. (In connection with rockets.) Burning of residual propellant after the end of the main blast. Afterburning that persists be-

yond the fuze arming period is conducive to random functioning of the early variety. Afterburning is aggravated by conditions such as low temperature or inadequate charge that bring about inefficient combustion of the propellant. The phenomenon of random functioning caused by afterburning is complex and not yet understood in full detail. For a thorough discussion of the subject, see Chapter 9.

5.1.4 Preparation of Fuzes for Use

For all fuzes that were produced on a large scale, Army and Navy manuals are available in which full details are given on the preparation of the fuzes for use. For the Army rocket fuzes see references 5 and 6. These fuzes are preferably checked shortly before use by means of field test equipment which is described in the bulletins. For the ring-type and bar-type bomb fuzes, instructions are given in reference 7. For Navy rocket fuzes, see reference 4. Some of the descriptive material in this chapter has been taken from these manuals.

5.1.5 Safety and Arming

All VT fuzes have two common safety features: (1) an off-line powder train, and (2) an interrupted electric detonator circuit. It is the purpose of the arming mechanism to line up the powder train and to complete the electric detonator circuit after the projectile has traveled to a safe distance. In considering the general characteristics of the various arming mechanisms, it is convenient to divide the fuzes into two classes: (1) fuzes for relatively nonaccelerated projectiles (bombs), and (2) fuzes for accelerated projectiles (rockets, mortar shells).

1. All the fuzes for relatively nonaccelerated projectiles have a windmill-driven generator and arming mechanism. In these fuzes the windmill or vane (see footnote *h* Section 3.4.5) must be turned a definite number of revolutions in order to arm the fuze, and also, after arming, the vane must be turning at a certain minimum rate in order to provide sufficient voltage to sensitize the fuze. For projectile speeds within a fairly wide range, the rotational speed of the vane is very nearly proportional to the speed of the projectile, so that the distance along the trajectory to arming is practically independent of the speed of launching. However, since the ratio of vane speed to projectile speed is not the same for all sizes and shapes of projectiles, the air travel to arming is not the same for all fuze-projectile combinations.

2. All the fuzes for accelerated projectiles are so designed that acceleration in the proper direction is required for arming. These fuzes will not arm if subjected to an acceleration that is substantially less than the minimum to be expected with the projectiles on which the fuzes are to be used. Furthermore, it is necessary that the acceleration should persist for a certain minimum time, i.e., that the projectile should attain a certain minimum velocity before arming can occur. Other arming requirements differ for the different types of fuzes, varying from a fixed arming-time requirement for Army rocket fuzes to a fixed air-travel requirement for mortar shell fuzes.

All fuzes having an arming vane are equipped with an arming pin which prevents the vane from turning until the projectiles are released.

An additional safety feature used on some models is the safety pin. The safety pin is inserted into the arming mechanism through an opening in the booster cup. The pin *cannot* be inserted unless the arming components are in the safe *unarmed* position. Each fuze comes supplied with this pin in place and the fuze cannot be inserted into the fuze well unless the pin is removed. A most important feature of the safety pin is that fuzes whose seals have been removed can have the arming mechanism checked for safety in the field.

The arming features are built into the fuzes and can be altered only by breaking seals or by other deliberate action. Although no adjustable arming mechanism is provided in the fuzes, it is possible to extend greatly the air travel required to arm most of the bomb fuzes by the use of an accessory device called an "arming delay" (see Figure 1 of Chapter 4). This device is set for the desired delay distance and

is clipped onto the bomb fuze. After the set delay distance has been traversed the delay device is thrown off, releasing the arming vane. From that point on arming proceeds in the usual fashion.

All fuzes are detonated by the discharge of a condenser through an electric detonator. After the condenser has been charged, it may remain charged for some time even if the source of electric power ceases to function. For this reason, fuzes which are known to have been armed, such as duds found on the ground, should not be handled for one hour after the vanes have stopped rotating. Duds should be handled only by qualified bomb disposal officers.

5.2 FUZES FOR THE ARMY 4.5-IN. ROCKET

5.2.1 General

Military Requirements

The Army M-8 rocket and the VT fuze for it were developed at about the same time under conditions of great urgency, primarily as a means of defense against bombing attacks. The VT-fuzed rocket was to be fired from fighter planes against bomber formations. Although the original requirement prior to development was for a 50 per cent fuze, it was required for production items that at least 65 per cent of the fuzes should function if the rockets passed within approximately 60 ft of a target plane. It was required also that the fuze should operate at a point on the trajectory such that effective use would be made of the lateral concentration of fragments from the rocket. Since the relative velocities of rocket and target, the angle of attack, and the structure of the target were all variable, it was not practicable to specify any sharply localized set of burst positions. In general, however, it was desired to have the rocket burst just before it arrived closest to the target plane (see Section 1.3).

The VT-fuzed rocket was later shown to have properties that made it adaptable for use in strafing operations or in ground artillery operations, but it was not designed for these purposes.

Although it is not within the scope of this report to detail the characteristics of the rocket, some remarks on this topic are required to permit a balanced assessment of the usefulness of the fuze. In particular it should be noted that the rocket was not adapted to precision shooting. As a result, even with a perfect fuze the probability of disabling an isolated enemy target plane would have been appreciably reduced by the dispersion.

Fuzes and Rockets

The T-5 and T-6 VT fuzes for the 4.5-in. Army rockets are intended for use as indicated in Table 1.

Table 1. Application of T-5 and T-6 fuzes.

Fuze	Use	4.5-in. rockets
PD, T-5	Plane to plane Plane to ground Plane to water	M-8, M-8A3, T-22, T-74, (M-8A1, M-8A1B1, M-8A2)*
PD, T-6	Ground to ground	M-8, M-8A3, T-22, (M-8A1, M-8A2)†

* Fuze T-5 should be used in these rockets only when the fins have been notched (see reference 6, paragraph 10), or when modified by 4.5-in. aircraft rocket kit T-23.

† T-6 fuze should be used on these rockets only when the fins have been notched (see reference 5, paragraph 10).

The fuzes T-5 and T-6 screw directly into all standard loaded 4.5-in. rockets listed in Table 1. They are directly interchangeable with the PD M-4 series of rocket contact fuzes both physically and ballistically. The fuze as issued is not complete. A battery must be installed prior to use. The standard components of a fuze are shown in Figure 12 of Chapter 4. Figure 1 shows 4.5-in. rocket M-8 fuzed with T-5. The fuze T-5 has a 1-sec arming time obtained through use of the switch *SW-230A or SW-230C, 1.0-sec arming*. The fuze T-6 arms in 3 to 6 sec, by using the switch *SW-230A or SW-230C, 5-sec arming*. The only other difference between the T-5 and T-6 is that the T-5 contains a self-destroying feature that will detonate the rocket approximately 6 to 12 sec after being fired if the fuze has not already functioned on a target.

General Limitations

The fuzes may be used during day or night and are not affected by fog or clouds. Heavy

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rain will increase the number of random functions and duds. On account of the use of dry cell batteries as a power supply, extreme temperatures must be avoided. Satisfactory operation

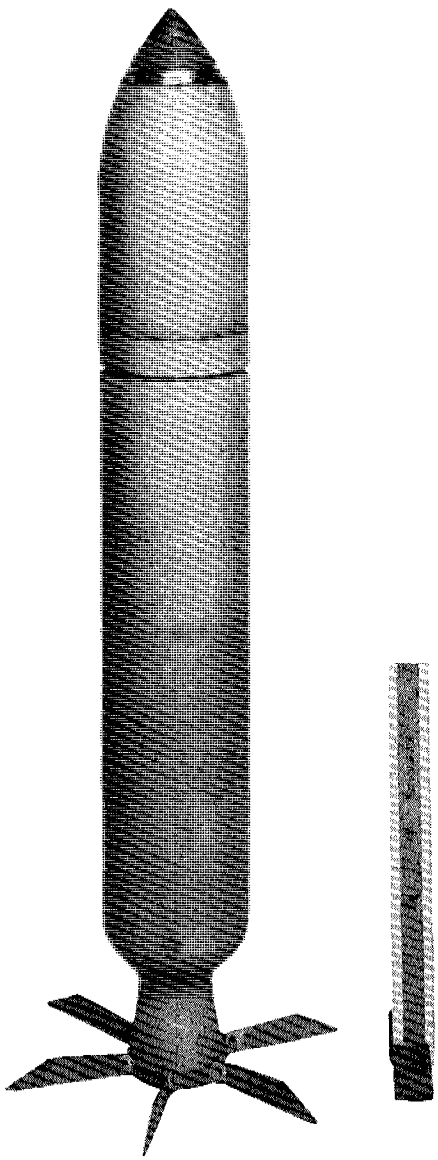

FIGURE 1. T-5 fuze on M-8 rocket.

can be expected in the temperature range from 20 to 100 F.

The fuzed rockets may be fired in ripple salvo without sympathetic functioning caused by random bursts.

The requirement for notching of the fins, mentioned above, is introduced because some of the M-8 rockets were manufactured with fins that did not lock in the open position. Any rattling or vibrating electric conductor on the surface of the rocket, which is part of the radiating system of the fuze, is likely to cause electric disturbances that will detonate the fuze. In notching the fins on the rockets that require this treatment, care must be exercised to avoid excessive twist of the fins. Otherwise the rockets may be caused to spin at a rate that will delay the operation of the arming switches (see following section). This precaution is of considerably greater importance in the use of the T-5 than in the use of the T-6 fuze.

The T-5 fuze is susceptible to random functioning under conditions that aggravate afterburning of the rocket propellant. One type of propellant trap that was used during the development of the rocket was found to be conducive to a high incidence of random functions about 2 sec after firing. This particular trap, characterized by a double ring of wire at the rear end, was not used in the final rocket design.

5.2.2 Functioning Characteristics

SAFETY, ARMING, AND SELF-DESTRUCTION

The arming of the fuzes is controlled by a mechanism that delays the arming for a certain period of time after the end of the acceleration that occurs during the burning of the rocket propellant. A detailed description of the mechanical arming is given in Chapter 4 and of the added RC arming in Section 3.3. The arming distance thus depends upon the velocity of the rocket prior to arming. The velocity of the rocket is dependent upon a number of factors, such as weight of the round, the amount and temperature of the propellant, and the speed of the plane if the rocket is fired from a plane. There are also variations from fuze to fuze in the arming distance, on account of tolerances permitted in manufacture. The reader is referred to Chapter 9 for a discussion of these factors. For the present purpose it is sufficient to give as arming distance the minimum distance at which arming will occur under any reasonable conditions of firing.

In determining the minimum range from which VT-fuzed rockets can be fired profitably, it is necessary to know the maximum arming distance, namely that distance at which all the fuzes will be armed. This distance also depends upon a number of factors, but a reasonable upper limit can be given.

The arming switch is so designed that it cannot be operated by violent jolts, nor can it be assembled into the fuze unless it is in the safe position. Although very unlikely, arming is not impossible in case of rocket blowup, and after such events fuzes should be disposed of only by trained personnel. This statement applies also to dud fuzes.

The self-destruction [SD] feature mentioned above is incorporated into the T-5 fuze primarily as a safeguard against operation as a ground-approach fuze when used over friendly territory in case it does not operate on a target.

The arming mechanism was not designed for a spinning rocket. As mentioned above, excessive twisting of the fins during the notching operation required by a few of the rockets can cause a spin that will interfere with proper switch operation. Experience has shown that if the fins are not twisted in excess of 2 degrees no trouble will be encountered (see Section 9.2 for details).

For the T-5 fuze, the risk of a random burst within certain specified distances is indicated in the following table.

Distance from launcher (yd)	Risk of random function (per cent)
175	nil
210	1
250	5

In aerial combat the position of the target plane will change appreciably during the arming of the fuze so that allowance must be made for the relative velocity of the attacking and target planes in estimating minimum firing ranges. A representative table of minimum firing ranges follows. At these ranges a negligible percentage of the fuzes are unarmed. The values given for broadside approach are applicable in plane-to-ground firing.

Minimum range (yd) for plane-to-plane use, both planes the same speed.

Plane speed (mph)	Pursuit	Attack from side	Head-on
300	243	390	537
400	235	430	625

For the T-6 fuze the probability of arming within certain specified distances is given below. The distances that are of practical interest are the horizontal distances for minimum quadrant elevation [QE].

Horizontal distances from launcher (yd)	Probability of arming (per cent)
840	nil
900	1
960	5

The minimum firing range is determined primarily by the need to use a QE large enough to carry the just-armed fuze so high that it will not function on the ground signal. The minimum QE and range are 8 degrees and 1,600 yd. Another reason for placing a lower limit on the QE is in order to avoid excessive burst heights (see following section on ground-to-ground firing of the T-6).

Proximity Bursts in Plane-to-Plane Firing of the T-5

The radius of action of the fuze is about 60 ft for attack on a medium bomber from the rear. For other forms of attack, it may vary somewhat, in the manner indicated in reference 6, Figure 2. On the average at least 75 to 85 per cent of VT-fuzed rockets within ROA can be expected to yield proximity bursts. The lower percentage is to be expected at extreme range on account of greater losses through random functioning during the longer flight.

The distribution of bursts about an airplane target is too complex for description here (see Section 9.2.3). In general it may be stated that for a round that passes very close to a part of the target, e.g., the tail, the burst will occur almost opposite that part of the target. For rounds that pass close to the ROA, the

[redacted]

burst is likely to occur about opposite the center of the target.

Plane-to-Ground Firing of the T-5

The mean burst height varies considerably depending upon the dive angle (see Figure 31, Section 5.5). It should be noted that for shallow dives the bursts are very high and widely scattered, diminishing considerably the accuracy of placement of the bursts and the damage to be expected. For best results, dive angles should be in excess of 30 degrees.

Ground-to-Ground Firing of the T-6

Variation in burst height with firing QE is shown in Figure 32, of Section 5.5. It may be seen that, for angles of 30 degrees or less, heights obtained over ground would center around 70 ft with a very large scatter. Effect-field tests have indicated that such a height would be excessive under most conditions. To obtain more satisfactory heights, therefore, firing elevations should be about 40 to 50 degrees.

5.2.3 Structure

General Arrangement

The nose member (MC-382) of the fuze, comprising the electronic system, is outlined by a hollow conical plastic shell mounted on a metal platform which supports the r-f oscillator block inside the shell (cf. Figure 12, Chapter 4). The amplifier section is potted inside a thick metal skirt which extends down from the platform. The tip of the conical shell is metallic and serves as antenna for the fuze.

The battery member (BA-75), outlined by an insulating container, comprises an axially located A supply cell nested in a cylindrical firing condenser which is surrounded by six stacks of B supply cells and one additional A supply cell.

The switch member (SW-230C), also cylindrical in outline, contains an acceleration-operated mechanism for closing the A and B circuits and for delayed closing of the firing circuit and alignment of the powder train. In the switch is located the electric detonator, a tetryl lead, and in some switch models a mechanical SD switch.

The nose and switch carry projecting connector pins and the battery, located between, has corresponding socket holes on each end. The three members, when plugged together, are screwed into a housing (M-381) which contains a tetryl booster charge at the bottom. This then comprises the complete fuze, T-5 or T-6.

Arming Mechanism

The arming process is completely controlled by the mechanism contained in the switch SW-230C. The mechanism is based on a new acceleration-integration principle developed at the National Bureau of Standards [NBS] and fully described in Chapter 4. The switch will not operate unless subjected to an acceleration greater than 75g in the proper direction for a time greater than 0.15 sec. (The principal elements of the switch are shown in Figure 5, Chapter 4.) In brief, the operation is as follows: The acceleration, acting on a weight eccentrically located on the driving shaft of the switch turns the shaft 90 degrees against the force of a 75-g spring. This motion is retarded by an escapement wheel and flutter-bar (see left-hand view in Figure 5, Chapter 4). At the end of the 90-degree turn, a spring-loaded rotary switch (center view) is allowed to snap shut (right-hand view), closing the A and B battery supply circuits of the fuze. When acceleration ceases, a rack-toothed slider-bar is driven by means of a pinion gear over to the other side of the switch, closing the firing circuit contacts which are located at the end of the slider channel, and also aligning a tetryl plug in the slider with an electric detonator which lies at the center of the channel. The motion of the slider is retarded by the same escapement mechanism to the extent of 0.7 sec or more. Additional arming is provided in some of the SW-230C switches by insertion of a resistor in the thyratron-condenser circuit. This delays the time at which the condenser will acquire sufficient energy to fire the detonator. Arming times up to about 6 sec are secured in this manner. The total arming time is stamped on the SW-230C switches.

[redacted]

Self-destruction of the T-5 is accomplished either by an RC circuit containing a special neon bulb NE-23 or by a mechanical switch. The circuit for the RC-SD consists of a 30-megohm resistor connected from B+ to a 0.25-mf condenser, the other side of which is grounded (see Figure 52, Chapter 3). From the common point of resistor and condenser, the neon bulb connects to the thyratron grid feed line at a point between R-15 and R-16. The mechanical SD is illustrated in Figures 4 and 10, Chapter 4.

R-F System

The oscillator diode [OD] circuit used in the T-5 and T-6 fuzes is shown in Figure 2. Values of the components are given in Table 2.

TABLE 2. Component values for oscillator in T-5 and T-6 fuzes.*

Resistor (R)	Value	Condenser (C)	Value (mmf)	Coil (L)	Notes
1	0.1 megohm	1	50	1	6 turns
2	15,000 ohm	2	50	2	6 turns
3	10 ohm	3	variable	3	5 turns
4	0.1 megohm	4	50	4	r-f choke
5	1.0 megohm	5	50	5	r-f choke
		6	50	6	r-f choke
		18	50		

Triode: QF 200 C or SA 780 A
Diode: QF 197

* Switches S1 and S2 are not located in the oscillator section, but in the SW-230 switch section; C18 is located in the amplifier section.

The oscillator components are assembled on a phenolic block much as illustrated in Figure 5, Chapter 6. The circuital relation of the components can perhaps be visualized better from Figure 13, Chapter 3. Both illustrations are actually of the T-50, as evidenced by the central hole for the generator shaft; exact details of the T-5 oscillator block are given in reference 1.

Amplifier

Except for a few minor elements, the amplifier circuit of the T-5 and T-6 fuzes is shown in Figure 25, Chapter 3, to which Table 3 applies. The missing elements are noted in the table.

TABLE 3. Component values for amplifier in T-5 and T-6 fuzes.

Resistor (R)	Value (megohm)	Condenser (C)	Value (mf)
6	1.0	7	0.02
7	0.15	8	50 mmf*
8	1.0	11	0.001
9	3.3	12	250 mmf
10	0.68	13	0.001
11	1.0	14	0.002
12	1.0	16	0.01
13	1.0	**Coil (L)**	**Turns**
14	3.3		
15	2.2		
16	0.1	5	70
17	4.7	6	19 in. of No. 32 advance wire wound on C9 (resistance and inductance shown in Figure 9)
19	0†		

Pentode: QF 206 or SA 781 A.‡
Thyratron: GL 489 (GE) or SA 782 B.†

* The following three 50-mmf by-pass condensers do not appear on Figure 9, Chapter 3: pentode grid, pentode filament, thyratron grid to ground.
† For SA 782 B, make R17 = 0 and R19 = 2.0 ohm.
‡ For SA 781 A, make R15 = 1.0 megohm, R9 = 4.7 megohm, and C14 = 0.005 mf.

5.3 FUZE FOR NAVY ROCKET AR 5.0

5.3.1 General

Military Requirements

The VT fuze designed for plane-to-surface application of the AR 5.0 rocket was required to give the following performance: (1) proper function scores should be on the average greater than 70 per cent, and (2) burst heights should lie within the range 10 to 100 ft.

Fuze and Rocket

Designations for fuze and rocket parts are as follows:

Fuze		Rocket	Motor	Head
T-2004 (Army designation)	Mk-172 Mod 0 (Navy designation)	AR 5.0	3.25-in. MK-7	5-in. MK-1

The fuze is a modified ring-type bomb fuze and in external appearance is identical with

the T-50 models. (It requires a larger cavity than the MK-149 or other rocket nose fuzes and is, therefore, not interchangeable with them.) See Figure 3 for complete round, T-2004 on AR 5.0. The principal structural change was the substitution of a setback gear train in place of the bomb fuze gear train. The function of this gear train is to complete mechanical arming at the end of the burning period. A second change was the introduction of a delay that prevented arming of the fuze until a certain time after burning of the propellant had ceased.

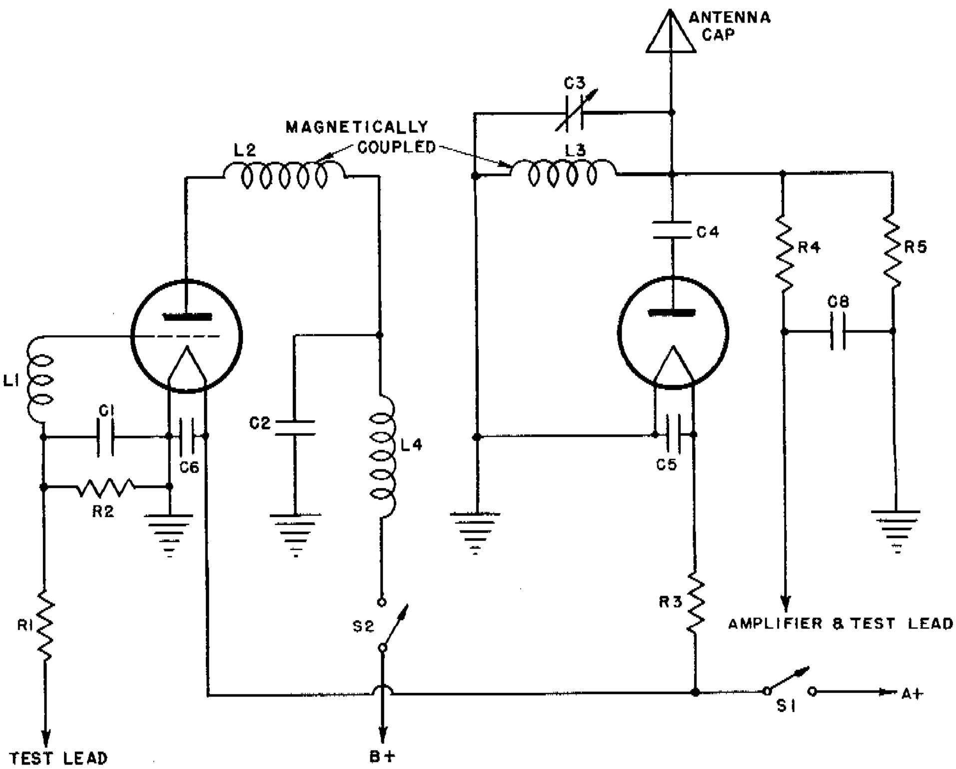

FIGURE 2. Oscillator-diode circuit used in T-5 and T-6 Army rocket fuzes.

General Limitations

The fuzes may be used at any temperature at which the rocket can be used. They are not affected by clouds, fog, snow, or light rain but may be affected by heavy rains or hail.

Afterburning of the rocket propellant may cause early functions if the fuzes are armed. Another effect of serious afterburning is to cause repeated dumping (see Section 3.3) of the firing condenser before it has sufficient energy to fire the detonator. In firing at short range, this can cause duds.

5.3.2 Functioning Characteristics

Safety and Arming

The mechanical arming mechanism is described fully in Chapter 4. Additional time delay in arming is introduced by charging the firing condenser through a resistor. The maximum and minimum arming distances are 1,500 and 1,000 ft when a 1.5-megohm resistor and 1.0-mf firing condenser are used.

From the standpoint of safety the actual distribution of early bursts is pertinent. Field test results give the following:

Early functions per cent of total rounds fired	Distance to burst (ft)
0	1,400
1	2,300
1.5*	3,200

* Based on 2,006 rounds.

The minimum release range (to insure arming) is a function of rocket temperature and

plane speed. The effect of these parameters on the minimum release range is shown in Figure 4.

Burst Heights

The average fuze is designed to function 30 to 40 ft above ground when fired from a plane in a 40-degree dive. However, functions at 15 to 60 ft (or considerably more over water)

Figure 3. T-2004 fuze on AR 5.0 rocket.

may be expected because of variations in the nature of the terrain and of variations among individual fuzes.

Curves showing variation of burst height with angle of dive are given in the data sheets of Section 5.5. Because of the dependence of range dispersion upon dive angle, values of 30 degrees or greater are recommended.

5.3.3 Structure

General Arrangement

The layout of the T-2004 is identical with that of the ring-type bomb fuzes (see Section 5.4.3).

Arming Mechanism

The arming scheme of the T-2004 is essentially the same as that of the ring-type bomb fuzes (Section 5.4.3) except for the mechanism that operates the slow-speed shaft and the introduction of RC delay, as used in the T-6 Army rocket fuze. The slow-speed shaft is controlled by a device that occupies the same space as the gear train of the bomb fuze but which is a combination of a gear train and an acceleration-operated system of levers and locks, as shown in Figure 29, Chapter 4. To obtain arming, the vane must turn a predetermined number of revolutions during an acceleration in the proper direction of more than $10g$. The spring-loaded slow-speed shaft is provided with a toothed lever arm which is entrained with the vane shaft by a worm gear system. If the vane is turned too much in the absence of adequate acceleration, the lever is forced against a lock, and the gear train strips at such a point that subsequent removal of the lock by acceleration will not free the slow-speed shaft. Adequate acceleration during the turning of the vane removes this lock. The weight which operates the locks is shown in the unaccelerated position (upper left of Figure 29, Chapter 4), and the accelerated position (upper right of figure). As soon as the slow-speed shaft is freed from the gear train, the spring rotates it 90 degrees. At this position further motion of the slow-speed shaft lever arm is blocked by a projection on the weight. As soon as acceleration falls to a low level, this block is removed, and the slow-speed shaft is snapped around by the spring an

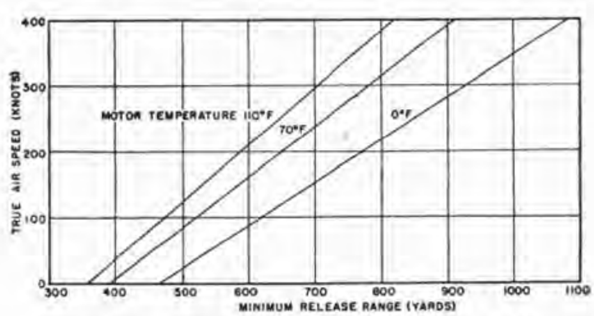

Figure 4. Minimum release range for T-2004.

additional 90 degrees into the armed position. Since there is no further motion of the shaft, a transfer pin is unnecessary, and the detonator rotor is permanently locked to the shaft.

The fuze is mechanically armed and the firing circuit is closed at the end of acceleration of the rocket. Detonation cannot occur until somewhat later, however, on account of the RC delay in the charging circuit of the firing condenser.

R-F System

The oscillator diode circuit of the T-2004 fuze is the same as that of the bomb fuzes containing the OD circuit (see Section 5.4.3) except for the addition of 50 mmf to the capacity of all the by-pass condensers.

Amplifier

The amplifier circuit of the T-2004 fuze is the same as that of the bomb fuzes (see Section 5.4.3), except for the addition of a 0.02-mf condenser and 0.33-megohm resistor in series from the pentode grid to ground, in order to reduce the gain of the amplifier. The resistors in the feedback network are altered to give a suitable peak amplification frequency and a number of minor changes in circuit component values are introduced. These changes are shown in Table 4 which gives values that differ from those of the amplifier No. 11 of the T-50-E4 bomb fuze (see Table 8).

Table 4. T-2004 amplifier component variations from T-50-E4 amplifier 11.

Resistor (R)	Value (megohm)	Condenser (C)	Value (mmf)
11	0.68	10	20,000
12	0.68	12	500*
		13	1,000
		14	2,000

* See text regarding addition to circuit.

Power Supply and Firing Circuit

The power supply and firing circuit (Figure 77, Chapter 3) used in the Navy rocket fuze is nearly the same as that used in the bomb fuzes. The main difference is the introduction of RC delay. The thyratron plate and one detonator contact spring are connected to B+ through a high-resistance R27 (0.51 megohm, nominal). The other detonator contact spring is connected, through the firing condenser C20, to ground. On completion of the detonator circuit, the firing condenser is charged at low current through the detonator. The other difference, made possible by improvements in condenser construction, is the use of an additional filter condenser, C23.

5.4 BOMB FUZES

5.4.1 General

Military Requirements

The military requirements for VT bomb fuzes may be classified as (1) requirements for GP fuzes, and (2) requirements for fuzes intended to be used for specific purposes (e.g., the enhancement of the blast effect of a certain bomb). Generally speaking, the requirements of the second kind were specified after the properties of the fuzes had been well established, and these requirements can be described with some accuracy. On the other hand, the requirements for GP fuzes did not remain fixed throughout the course of development, and the description of these requirements cannot be given completely without introducing an undesirable amount of historical detail.

This is particularly true in the case of the ring-type fuzes. For example, the initial requirements of uniformity of burst heights were such that engineering calculations indicated that it would be necessary to manufacture ring-type fuzes in three different carrier-frequency bands in order to cover the specified range of bomb sizes. Certain compromises were made and the ring-type fuzes were manufactured in only two carrier bands. Later, the addition of Navy requirements to the existing Army requirements led to the manufacture of two types of fuzes in each carrier band.

Largely as a result of knowledge gained from effect-field tests, and service experience on the relative usefulness of different types of bombs, it gradually became apparent that uniformity of burst heights for a wide range of bomb sizes and release conditions was not so important as had originally been supposed. In essence, it was concluded that under many conditions the effectiveness of an air burst was so much greater than that of a ground burst that close control on the height of the air burst was of relatively minor importance. This conclusion played an important part in the decision, made shortly before the close of World War II, to reduce the number of ring-type bomb fuzes in production from four to one.

The difficulty of adequately treating this sub-

ject is further enhanced by some differences in military opinion on the usefulness of different applications of the fuzes. For example, although in certain quarters it was concluded that the fuzes would be of little use in attacking well-entrenched positions, the fuzes were actually used most frequently against antiaircraft positions, and the results reported by the users were, on the whole, very satisfactory.

For the purposes of this report, the following general requirements are presented as adequate to specify fuzes that are useful under a rather wide variety of service conditions.

Reliability. The fuzes should give, on the average, proper functions in excess of 70 per cent when release is made at any altitude from that required to ensure arming up to at least 20,000 ft. This performance should hold for all train spacings in excess of a minimum determined by a reasonable area of effectiveness of a single bomb of the train.

Burst Heights. Under the conditions just stated, the great majority of proper functions should lie within the range 10 to 100 ft above the target area. This implies that the average height of proper functions should lie within the range 15 to 50 ft above the target area, regardless of release conditions within the limits stated above.

Safety and Arming. The fuzes should be at least as safe to use as the safest of all other types of bomb fuzes. None should arm before traveling the *minimum safe air travel* [MinSAT] specified for the particular type of fuze, and practically all should arm within ±10 per cent of the mean air travel to arming of the particular bomb-fuze combination under consideration.

General Types

As mentioned above (see Section 5.1.2) bomb fuzes may be divided into two major groups on the basis of the antenna system—the ring type and the bar type. Another type of classification is based on the r-f circuit. In this system, the classification depends upon whether detection is accomplished by a tuned diode detector [OD], by a reaction grid detector [RGD] or by a power-oscillating detector [POD]. This section will explain both types of classification and describe the general operational characteristics of each group.

Ring and Bar. The external differences between the ring and bar type are shown in Figure 5, Chapter 1. The antenna system of the ring type consists of the ring of the fuze together with the body of the bomb. This type of excitation is known as longitudinal excitation. The antenna of the bar type consists of the two bars on the fuze, and does not theoretically include the bomb itself. Actually, there is usually some slight excitation of the bomb. This type of excitation is known as transverse. See table below for listing of fuzes of the two types.

Bar-type fuzes may be expected to give better scores (less random functions) than most ring-type, for two reasons. (1) Since the vehicle is relatively unexcited in the bar type, any mechanical disturbance, such as fin flutter, will affect the radiation only very slightly; and (2) bar-type fuzes have either RGD or POD circuits, which, as will be shown later, are less susceptible to noise disturbances than the OD.

One of the most marked differences between the two types is the much greater burst height possible with the bar type. This difference is due to the orientation of the radiation directivity pattern, which differs by 90 degrees for the two types. For an antenna short compared with a wavelength, the maximum radiation is at an angle of approximately 90 degrees with the axis of the antenna, and the minimum along the axis. Since the antenna of the bar type is perpendicular to the axis of the bomb, the maximum radiation is along the bomb axis. Therefore, the bar-type fuzes have their maximum sensitivity directly forward. Since for most release conditions the angle the bomb makes with the vertical is very small, this high forward sensitivity aids in the obtaining of large function heights. Ring fuzes, on the other hand, have their maximum radiation roughly perpendicular to the bomb axis and low radiation at the small angles encountered in level flight release from high altitudes. The ring fuzes are therefore sensitive to objects they pass while the bar fuzes are sensitive to objects directly ahead. As a result, bar fuzes give much higher heights for level-flight release conditions when the bomb is close to vertical.

[redacted]

Key to bomb fuzes

Ring type		Bar type	
Brown	White	Yellow	White
OD circuit		RGD circuit	POD circuit
T-50-E1	T-50-E4		
T-89	T-90	T-51	T-82
T-91	T-92	T-51-E1 (M-166)	Series
RGD circuit		T-51-E2	
T-91-E1 (M-168)	T-92-E1	T-712	

R-F Circuit. The operational differences between fuzes having the OD, RGD, or POD circuits are less marked than those based on the antenna system, but they are significant. In general, better scores may be expected from RGD and POD than from OD circuits. The tuned diode detector circuit is much more sensitive to frequency modulation (usually produced by microphonics) than the RGD or POD circuits. Another factor influencing OD performance is tuning of the OD circuit, which is different on each bomb. Hence the diode circuit cannot be perfectly tuned on every vehicle. Since both r-f sensitivity and noise-response depend on tuning, there will be more spread in both height and scores for OD units on different vehicles than for RGD.

The RGD circuit, therefore, is less susceptible to noise disturbances, particularly tube microphonics, than the OD and performs more uniformly on different vehicles.

Specific Applications

VT bomb fuzes may be divided into two categories, depending upon mode of flight during release. Three fuzes, T-91, T-91-E1, and T-92 were designed with short arming time (2,000 to 2,600 ft MinSAT) specifically for dive bombing and low-release altitude; all other fuzes (with 3,600 ft or greater MinSAT) for level flight release.

Specific applications of these fuzes may be divided into two groups: (1) those depending upon the effect of the blast associated with the bomb burst, and (2) those depending upon the effectiveness of fragments from the bomb and its contents. In Table 5 (a) and (b) are of the first type and (c) through (f) the latter. The recommended type of fuze and most desirable burst height are given along with estimates of effectiveness as compared with similar use of a contact fuze.

With the exception of the first and last applications listed below, the M-166 and M-168 fuzes may be regarded as adequate to meet all the applications listed. The M-166 is suitable when large burst heights are needed and the M-168 for low burst heights or for dive-bombing applications. The earlier models have been listed merely for completeness.

5.4.2 Functioning Characteristics

Safety and Arming

MinSATs Available, Normal Arming. VT bomb fuzes have been designed with minimum safe air travels of 2,000, 2,600, 3,100, 3,600, 4,500, and 8,000 ft. Of these MinSATs, how-

Table 5. Applications of bomb fuzes.

Application	Burst height (ft)	Estimated advantage	Fuze
a. Blast effect, M-56	40–70	1.5 to 2	T-712
b. Mine clearance by blast from Mk-44	10–20	Up to 2	T-50 type
c. General purpose (antipersonnel and light matériel)			
1. For 500- and 1,000-lb bombs	20–70	1 to 20	T-90, T-50-E4, T-92*
2. For bombs smaller than 500 lb and others up to 2,000 lb	20–70	1 to 20	M-166, M-168, T-50-E1, T-89, T-91
3. For all vehicles	20–70	1 to 20	M-166, T-51-E2
d. Chemical warfare (gas)	100–200	4 to 7	M-166, T-51-E2
e. Fire bombing			
1. For 165-gal belly tank	40–80	2	M-166, T-51-E2
2. For M-10 spray tank	5–15	2?	T-90, T-50-E4

* The T-92 is listed last on account of inferior reliability (see Section 5.4.2).

[redacted]

ever, only three were used on fuze types reaching the production stage. These were:

MinSAT	Production type
2,000 ft	T-91, T-91-E1 (M-168); T-82-E2
2,600 ft	T-92
3,600 ft	T-50-E1, T-50-E4; T-51-E1 (M-166), T-51-E2; T-82-E1; T-89, T-90

Data on the safe vertical drop and minimum release altitude corresponding to different MinSATs under various conditions are tabulated in reference 7. The types with 2,000-ft and 2,600-ft MinSATs were intended specifically for dive-bombing applications.

MinSATs Available, Delayed Arming. The air travel to arming on all the above types (except the T-82-E1) can be extended by the use of the device *arming delay, air-travel, M-1* (formerly T-2-E1), which will provide up to about 20,000 ft of additional air travel to arming for any fuze adapted for holding it. The arming delay device is a wind-driven vane mechanism which is clamped on the fuze in such a way as to prevent rotation of the fuze arming vane (see Figure 1, Chapter 4). When the delay vane has rotated through a preset number of revolutions (manually adjustable in the field), the delay disengages itself from the fuze, allowing the fuze arming mechanism to operate in the normal fashion. The arming delay is constructed with a setting dial containing 25 divisions, each of which corresponds to about 800 ft of air travel on the M-30 test bomb. Data on arming delay settings under various conditions are given in reference 7.

Effect of Bomb Size on Air Travel. For a given rotor setting the air travel to arming generally increases with the bomb size. This effect is due to the additional obstruction offered by the larger bomb nose to the flow of air past the vanes. The relative air travel for different vane types on various vehicles is as follows:

Vane	Bomb		
Metal and plastic	M-30 100-lb GP 1.00	M-81 260-lb frag 1.02	M-64 500-lb GP 1.15
Vane	Bomb		
Metal and plastic	M-65 1,000-lb GP 1.32	M-66 2,000-lb GP 1.58	M-56 4,000-lb GP 1.48

Safety Pin. Booster cups on the production-type fuze models, with the exception of T-50-E1, T-50-E4, and T-51-E2, are equipped with a safety pin for indicating that the fuzes are safe for handling. The pin locks the arming mechanism and can be inserted only if the detonator rotor is in the unarmed position. Fuzes are issued with the safety pin in place and cannot be installed in the fuze-well unless the pin is removed.

Reliability

With few exceptions, ring-type fuzes released under standard test conditions (from 10,000 ft at 200 mph), can be expected to give uniform performance of about 75 to 80 per cent proper functions. The M-168 fuzes should give consistently better scores (about 90 per cent proper). The performance of T-92 fuzes was not satisfactory (an average of only 58 per cent proper functions was obtained in experimental and acceptance tests). A possible explanation for the increased incidence of early functions may be found in the fact that the T-92's were built with broader pass-band amplifiers and were more sensitive than the other fuzes. The fuze appeared to be unduly susceptible to certain structural variations in standard bombs. The effect of fin thickness on fuze performance is discussed in Chapter 9.

Fuze performance is dependent to some extent upon altitude of release. Scores will generally be slightly poorer for release altitudes above 10,000 ft than under standard release conditions; on the other hand, performance can be expected to improve somewhat with lower release altitudes.

Bar-type fuzes, on the whole, should give better performance than ring-type fuzes, except the M-168. Under standard release conditions, proper function scores of T-51 and T-82 type fuzes should fall close to an average of 90 per cent.

The possibility of sympathetic functioning must be considered when proximity fuzes without arming delays are released in train. If the spacing between bombs is too small, one armed fuze may react upon the random burst of another. The train spacing should exceed 50 ft on the ground for small bombs (less than 500 lb), and should exceed 100 ft for large bombs.

Train spacing is unimportant if arming delays are used because the delays postpone arming until the bombs are widely spaced.[8] These devices can be used on most models (see Section 5.4.2).

Burst Heights

Burst heights of VT bomb fuzes are affected by a number of factors external to the fuze, such as vehicle, altitude of release, plane speed, and target factor.

Ring Type. Proper function heights of ring-type fuzes under standard test conditions (i.e., dropped over water from 10,000 ft at 200 mph) can be expected to lie between 10 to 100 ft, with average heights ranging from 15 to 50 ft. Satisfactory uniformity of burst heights in the same range should be obtained for fuze-vehicle combinations recommended in the fuze data sheets below. Lower function heights will result from the mismatching of vehicle and fuze. The effect of release altitude upon burst height is not simply defined. For some fuzes, such as the T-89, averages of proper function heights can be expected to increase with increasing altitudes of release; for other fuzes, the reverse is true (see Figures 9 and 21).

Bar Type. The forward sensitivity pattern of bar-type fuzes causes much higher burst heights than those obtained with the ring-type fuze. Function heights as high as 240 ft above water are considered proper for T-51 and T-82 type fuzes, released under standard conditions. Average function heights of 50 to 100 ft over land can be expected from either fuze mounted on M-81. Theoretically, performance of bar-type fuzes should be nearly independent of vehicle; however, lower burst heights will be produced by fuzes mounted on 500-lb bombs and larger (with the exception of the T-51 on M-56) than by fuzes mounted on 100- to 260-lb bombs. For burst heights of bar-type fuzes on various bombs relative to burst heights on M-81, see Table 14.

5.4.3 Structure

General Arrangement

The general layout of all bomb fuzes (except the T-82 series) is illustrated in Figure 17, Chapter 4. Except for the much larger antennas (ring or dipole bars) and the introduction of an axially located drive shaft running from the vane through the electronic system, the front section is practically identical with that of the Army rocket fuzes T-5 and T-6. The battery of the T-5 is replaced by a magneto-type generator, a gear-reduction system, and most of the components of a rectifier-filter system for the generator, all in about two-thirds of the fuze length required for a battery. At this level, the fuze housing is shouldered in to seat on the nose of the bomb. The narrower extension of the housing contains a cylindrical filter and firing condenser, through the center of which runs a slow-speed shaft from the gear-reduction system to the terminal elements of the arming mechanism. The housing is closed at the rear end by a threaded cup containing a booster charge of tetryl.

All bomb fuzes are shipped completely assembled and loaded and require no field testing or assembly operations such as those required with the battery-powered T-5 and T-6.

Arming Mechanism

The principal elements of the arming mechanism of all bomb fuzes (except the T-82 series) are shown in Figure 20, Chapter 4. A worm-gear train drives a slow-speed shaft to which is keyed a Bakelite detonator rotor by means of a spring-loaded transfer pin. The detonator rotor carries an electric detonator, eccentrically located in a hole as shown in the rear-end view, Figure 24, Chapter 4. The rotor rides in a Bakelite housing which is mounted on the rear end of the rectifier filter assembly shown in Figure 27, Chapter 4. This housing serves two purposes: it has a slot that permits the spring-loaded transfer pin to leave the slot in the slow-speed shaft after the rotor has turned a predetermined angle, thus locking the rotor in the armed position; it carries electric contact springs that complete the detonator circuit immediately before the rotor is locked in place. In the unarmed position, the tetryl booster charge is protected from the detonator by a thick brass safety plate. This plate carries a tetryl plug to which the detonator is juxtaposed in the armed position.

All bomb fuzes are provided with a vane-locking pin, or equivalent device, from which is withdrawn an arming wire when the bomb is dropped (see Figure 20, Chapter 4).

A safeguard that was necessary on the earlier models was the closed slot on the slow-speed shaft. In order to prevent assembly with an incorrect rotor setting, the keyway is not extended to the end of the slow-speed shaft. The rotor housing is notched at the proper angle from the armed position, and the transfer pin can be pressed into the keyway of the slow-speed shaft only when this keyway is aligned with the notch. An incorrect setting can be obtained in these models only by rotation of the vane, the locking pin of which was sealed in place before assembly.

This safeguard was unnecessary in the later models, which are provided with a safety pin (see Figures 23 and 24, Chapter 4) which can be inserted into and withdrawn at will from the completely assembled fuze only if the detonator rotor is in the correct position.

The data sheets (see Section 5.5) tell which of these additional safety features appear in each of the production model fuzes. The possibility of using the arming delay device is also indicated in Section 5.5. The purpose and method of using this auxiliary device has already been outlined in Section 5.4.2 above. Its construction and operation can be readily visualized from Figure 1, Chapter 4.

R-F System

Oscillator-Diode [*OD*] *Circuits.* The OD circuit used in bomb fuzes is nearly the same as that used in the Army rocket fuzes T-5 and T-6 (see Figure 2). In the bomb-fuze diode circuit, R5 is connected to the other side of C4 instead of to ground. No switches are used in the A and B supply lines, the resistance in the diode filament line is increased to 10 ohms, and the capacity of the by-pass condensers C2, C5, and C6, is increased to 150 μμf each. Another 150-μμf by-pass from the B supply line to ground is located in the amplifier section of the fuze.

The Reaction-Grid-Detector [*RGD*] *Circuit.* The RGD circuit is used in the M-168 and the T-92-E1 ring-type bomb fuzes (see Figure 5). Component values are given in Table 6.

Table 6. Component values for RGD oscillator in M-168 and T-92-E1 fuzes.*

Resistor	Value (ohms)	Condenser	Value (μμf)
R1	100,000	C1	5
R2	47,000	C2	30
R3	2,200	C3	30
		C4	5
		C6	150
		C22	150
	Triode:	NR3A	

* L1 and L2 are adjusted to obtain required frequency and sensitivity. C22 is located in the amplifier section.

The RGD oscillator used in the M-166 bar-type bomb fuze is shown in Figure 6. Values of components are given in Table 7.

Table 7. Component values of RGD oscillator in M-166 fuze.*

Resistor	Value (ohms)	Condenser	Value (μμf)
R1	1,000	C1	25
R2	3	C2	50
R3	33,000		
R4	47,000		
	Triode:	NR3A	

* L1: oscillator and antenna coils wound on same core. L2: r-f choke.

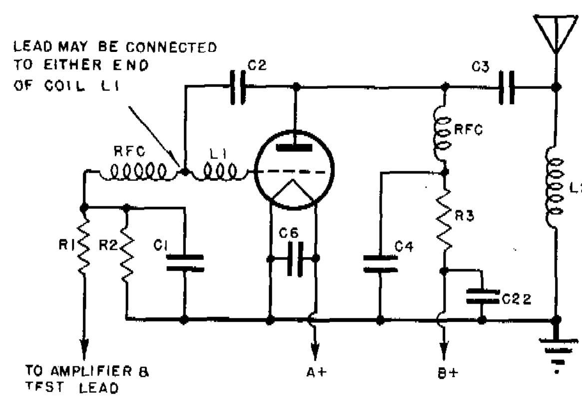

Figure 5. Reaction-grid-detector circuit used in M-168 and T-92-E1 bomb fuzes.

Oscillator Assemblies. With the exception of the T-82, the physical layout of the oscillators in all bomb fuzes is nearly the same. The mounted components and their circuital relationships are illustrated in Figures 13, 14, and 15, Chapter 3. Phenolic (thermosetting) mounting blocks (Figure 5, Chapter 6) were used in all except the M-166, in which a sty-

[redacted]

ramic (thermoplastic) block was used (Figure 6, Chapter 6).

Amplifier

Circuits in Ring-Type Fuzes. The basic amplifier circuit of all ring-type bomb fuzes is shown in Figure 26, Chapter 3. Table 8 provides the component values for the No. 11 amplifier of the T-50-E4 and notes on minor differences from the circuit shown in the figure. Table 9 shows the differences that occur in other amplifiers of this series.

Table 8. Component values for amplifier No. 11 in T-50-E4 fuze.*

Resistor	Value (megohms)	Condenser	Value ($\mu\mu$f)
R7	0.68	C7	5,000
R9	5.6	C8	3–20
R10	1.0	C10	5,000
R11	1.5	C11	500
R12	0.47	C12	200
R13	2.2	C13	200
R14	6.8	C14	1,000
R15	2.2	C15	500
R19	3 ohms	C16	50
R21	6.8 ohms		
R30	1.0		
	Pentode: NS-5		
	Thyratron: NS-4		

* C16 is optional; may be connected between ground or filament and any part of the input circuit to minimize r-f effects. Additional items in amplifier section: a test lead brought out from the thyratron grid; 150-$\mu\mu$f by-pass condenser from B+ to ground.

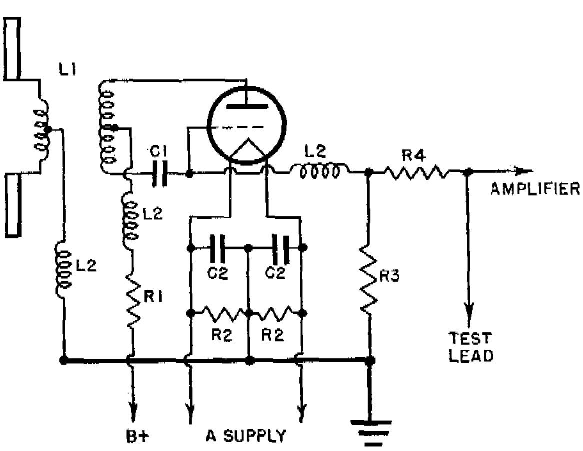

Figure 6. Reaction-grid-detector circuit used in M-166 bomb fuze.

Circuit in Bar-Type Fuze. The basic amplifier circuit of the M-166 (T-51-E1) bar-type bomb fuze is shown in Figure 30, Chapter 3, for which Table 10 provides the component values.

Table 9. Variations from amplifier No. 11 (T-50-E4) in other ring-type bomb fuzes.

Fuze / Amplifier	T-50-E1 T-89 No. 10	T-91 M-168 No. 20	T-92 No. 16	T-92-E1 No. 18
Resistor (values in megohms)				
R11		...*		1.68*
R12	0.82	1.5*	0.82	0.68*
Condenser (values in $\mu\mu$f)				
C7	10,000			2,000
C8	5–20	0–20		0–20
C10	20,000	20,000		20,000
C11		200		200
C12		500		500†
C13	500	500		500
C14	2,000			2,000
C15			300‡	200§

* Adjust to obtain required frequency.
† Feedback loop connection is shifted from pentode plate to the thyratron grid side of C14.
‡ A 200-$\mu\mu$f condenser is connected from the input line to ground.
§ Feedback loop resistors R11 and R12 connected to center point between the legs of pentode filament by two 1,000-ohm resistors.

Table 10. Component values for amplifier in M-166 (T-51-E1) fuze.*

Resistor	Value (megohms)	Condenser	Value ($\mu\mu$f)
R2	3 ohms		
R5	0.39	C3	0.005
R6	1.0	C4	50 $\mu\mu$f
R7	0.47	C5	0.01
R8	1.0	C6	0.0002
R9	5.6	C7	0.0004
R10	2.2	C8	0–20 $\mu\mu$f
R11	3 ohms		
	Pentode: NS-5, NR-5 or NGE-5		
	Thyratron: NS-4		

* Not shown in Figure 30, Chapter 3: A test lead brought out from the thyratron grid; each side of the A supply line is grounded (in the oscillator section) by a 3-ohm resistor shunted by a 50-$\mu\mu$f by-pass condenser.

Amplifier Assemblies. A number of different types of amplifier assemblies are found in the bomb fuzes. These are illustrated in the following figures in Chapter 6: Figure 17, right, for Philco models; Figure 17, left, for Emerson models (both are disk variations of the sandwich type of assembly); Figure 14 for the Zenith M-166 ("dog collar" type of assembly).

[redacted]

For reasons discussed in Chapter 6, the type of assembly used is, generally speaking, a characteristic of the manufacturer rather than of the fuze, and a more detailed description is unwarranted here.

In all bomb fuzes, the thyratron is included in the amplifier assembly. Tung oil was used as a potting material for the amplifier assemblies, except for late Emerson production, for which Glidden potting compound was used.

Power Supply and Firing Circuit

The power supply and firing circuit used in bomb fuzes is shown in Figures 75 and 76, Chapter 3. The lead from the thyratron plate [TP] tap is connected to one of the spring contacts in the detonator rotor housing; the other spring contact is connected to B+ and through the firing condenser C20 to ground. The filter condenser is C19, and C18 is the voltage regulation condenser.

5.5 PRODUCTION FUZE DATA SHEETS

5.5.1 Scope

The following set of data sheets covers information, where available or pertinent, for production fuzes only, in the following order:

Item 1. Tabulations of arming, electrical, and performance data.

Item 2. Curves of burst-height performance.

Item 3. Amplifier gain curves.

Item 4. Radiation patterns and loading curves.

The T-51-E2 has been omitted, since it represents only about 4 per cent of the total bar-type production and its characteristics were practically the same as those of the Zenith M-166, except that it lacked the safety pin.

The T-712, although produced on an even smaller scale than the T-51-E2, has been included because certain of its characteristics are quite different from those of other bar-type fuzes. It is understood that its production was limited on account of the limited supply of M-56 bombs.

Coverage in this section has been limited to production items because these are the only fuzes which are in stock in appreciable quantities.

Explanatory Notes

Item 1.

(a) In the *tabular data,* entries are omitted if all in a row are repetitions of that in the first column.

(b) *Electrical data* represents overall production averages as shown on CTL Quality Control Charts, where available.

For longitudinally excited fuzes, the maximum sensitivity is given; the approximate load resistance R (in 10^3 ohms) at which maximum sensitivity occurs appears in parentheses after the sensitivity value. For OD circuit fuzes, the sensitivity S' at any other load R' can be calculated with sufficient accuracy from the formula

$$\frac{S'}{S} = \frac{4RR'}{(R+R')^2}.$$

For the RGD circuit, this formula is less accurate, and loading curves are given where available.

The laboratory data on detuning apply to OD circuit fuzes as tested with a standard load approximately equivalent to that presented by the missile for which the fuze was designed. For bomb fuzes, the bombs represented in the laboratory tests were M-30 for Brown frequency and M-64 for White. For information concerning the effect of detuning on sensitivity, see Section 2.7.

Effective critical voltages are the maxima obtained in the detuning tests.

(c) Function scores are averaged without regard to reflection coefficient or plane speed but are restricted to missiles, as stated in Table 11. The very few *late functions* are included with the proper functions.

Function heights are for release from 10,000 ft at a plane speed of 200 mph over water with a reflection coefficient of approximately 0.81, unless otherwise indicated by footnote. Part of the original data were obtained under other conditions. The method of reduction to a common condition is covered in Section 9.4.

(d) Under *production,* the quantities given are the approximate number of metal parts (MP) lots produced, usually about 1,000 units per lot.

(e) The AN/CPQ-( ) designation system was originally set up to distinguish between vane leads, arming distances, rotor settings, etc., in different metal parts assemblies as delivered from the factory. Later it became necessary to make changes in the rotor settings in assembling some of the metal parts products into complete fuzes at Picatinny Arsenal, so that the AN/CPQ designations lost their significance in some cases. However, since this nomenclature was used almost exclusively in the many reports of the Control Testing Laboratory at the National Bureau of Standards, it has been recorded here as an aid to anyone who has occasion to study the laboratory performance of production models. The lack of a complete 1-to-1 correspondence between metal parts designations and fuze (T- or M-) designations is unavoidable.

Item 3. The PkAF and peak gain as appearing on the curves are not always consistent with the audio-frequency at peak amplification [PkAF] and millivolts to fire [MvF] at peak given in the tabular data, because considerably smaller samples were used in determining the amplifier characteristics. The curves can be relied upon for shape but should be adjusted for location of peak.

Item 4. Only those radiation patterns that are most likely to be useful in the calculation of burst heights have been included; for other patterns and much useful additional data for this purpose, see reference 3.

Abbreviations.

MinSAT: Minimum safe air travel, during which no fuzes will arm.

CF: Carrier frequency of the fuze transmitter.

S: Sensitivity, as defined in Section 3.1.2.

Amp. No.: Signal Corps identification number of amplifier.

PkAF: Audio-frequency at peak amplification.

MvF: Millivolts to fire (the thyratron) applied at amplifier input.

CV: C-bias voltage on the thyratron.

EC: Effective critical voltage, at which bias voltage the thyratron fires.

Rel gain: Relative gain of the amplifier.

SD time: Self-destruction time.

Data Common to Production VT Bomb Fuzes

Table 11. General purpose models.

Property	Fuzes		
	Ring-type		Bar-type
	Brown	White	
	T-50-E1, T-89, T-91, T-91-E1 (M-168)	T-50-E4, T-90, T-92	T-51-E1 (M-166)
Physical characteristics:			
Overall length (in.)	$10\frac{1}{32}$	$10\frac{1}{32}$	$10\frac{1}{32}$
Length from shoulder (in.)	$4\frac{15}{16}$	$4\frac{15}{16}$	$4\frac{15}{16}$
Overall width (in.)	$3\frac{3}{8}$	$3\frac{3}{8}$	10
Weight (lb)	4	4	4
Vane speed range* (1,000 rpm)	15–30	15 30	20–35
Proof test conditions:			
Bomb	M-81, -88	M-64	M-57, -81, -88
Release alt. (ft)	10,000	10,000	10,000
Uses:			
Physically interchangeable with contact fuze	M-103	M-103	M-103
Some bombs for which the fuzes are useful	GP: M-30, -57, -66 Frag: M-81, -88	GP: M-64, -65	GP: M-30, -57, -64, -65, -66 Frag: M-81, -88

* Laboratory test speed range.

[redacted]

5.5.2

Bomb Fuzes, Ring Type, Brown Carrier

TABLE 12. Characteristics and scores.

	Level or dive release			Level release	
	M-168 (T-91-E1)	T-91		T-89	T-50-E1
Arming					
MinSAT (ft)	2,000	2,000	2,000	3,600	3,600
Safety pin	Yes	Yes	Yes	Yes	No
Delay device	Yes	Yes	Yes	Yes	Yes*
Rotor setting (°)	65	65	65	110	100
Rotor shaft	Open	Closed	Closed	Closed	Closed
Vane	10-blade metal prop		.....	.....	.....
Vane angle (°)	55	.....	.....	.....	.....
Electrical					
Radio					
Circuit	RGD	OD	OD	OD	OD
CF	+0.9	−1.5	+1.1	−1.5	−1.5†
S (volt)	30 (5)	16 (5.5)	18 (5.5)	16.5 (5.5)	16.5 (5.5)
Detuned (%)	.....	3	4	4	4
Audio					
Amp. No.	20	20	20	10	10
PkAF (c)	93	94	97	116	116
MvF (Pk)	23	25	25	26	26
CV (−volt)	7.7	8.2	7.6	8.4	8.4
EC	3.8	4.9	4.3	4.8	4.8
Proof performance					
Burst height (ft)	50	37	44	35	35
Proper (%)	92	87	84	83	83
Random (%)	7	11	10	13	13
Dud (%)	1	2	6	4	4‡
Production					
Manufacturer	Emerson	Philco	GE	Philco	Philco
Quantity (MP lots)	27	70	50	10	130
AN/CPQ-	2C				
PA-	329	307	307	263	180

* Not loaded with fuzes. † First 50 MP lots manufactured at +2, excluded from average. ‡ 19% dud on first sample tests of the first 42 lots, due to faulty rotor contact spring adjustment. Not included in average.

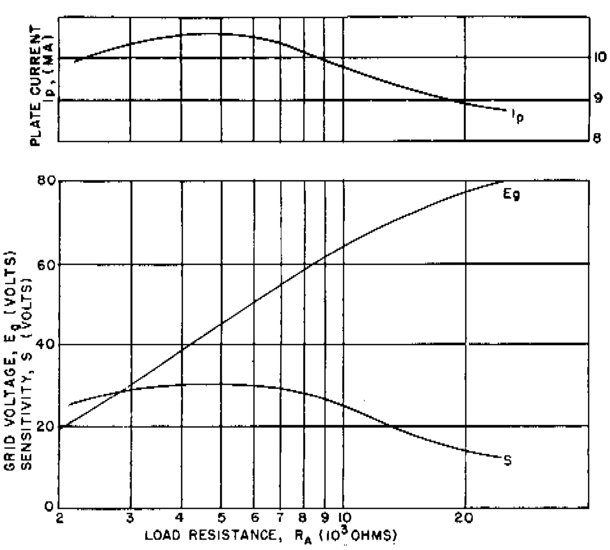

FIGURE 7. Oscillator loading characteristics of M-168 bomb fuze. Plate current I_p, grid voltage E_g, and radiation sensitivity S are shown as functions of radiation resistance R_a.

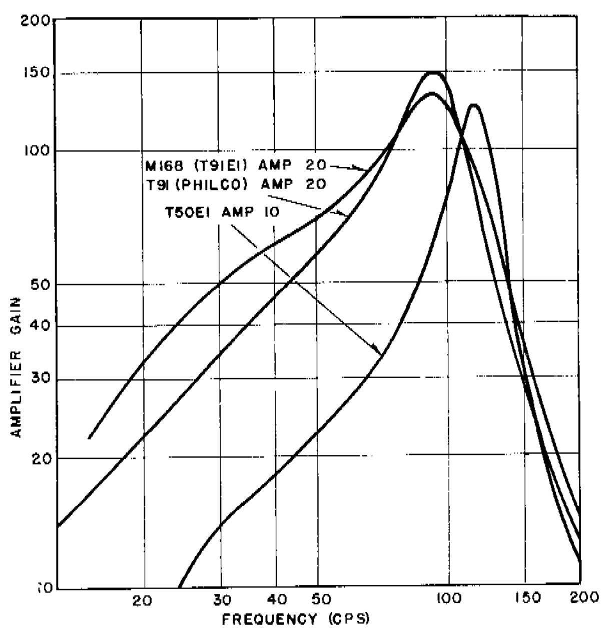

FIGURE 8. Amplifier gain as function of signal frequency for ring-type Brown-carrier bomb fuzes.

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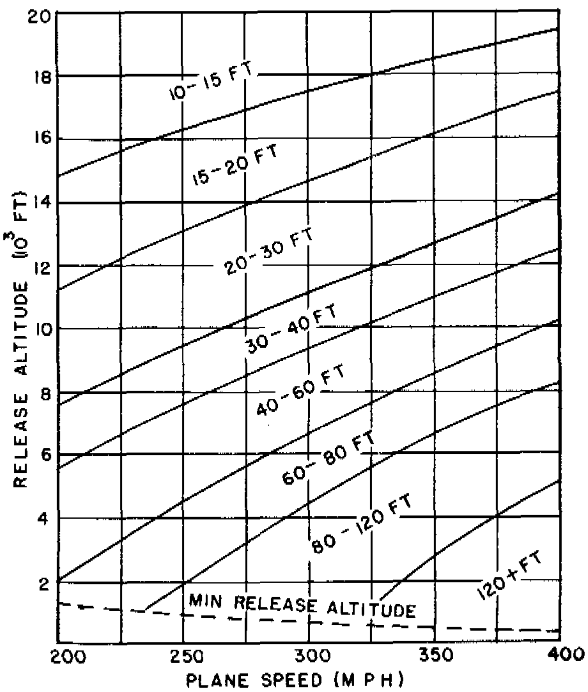

FIGURE 9. Iso-burst-height curves (predicted) for M-168 fuze on M-64 (500-lb) GP bomb for reflection coefficient of 0.5.

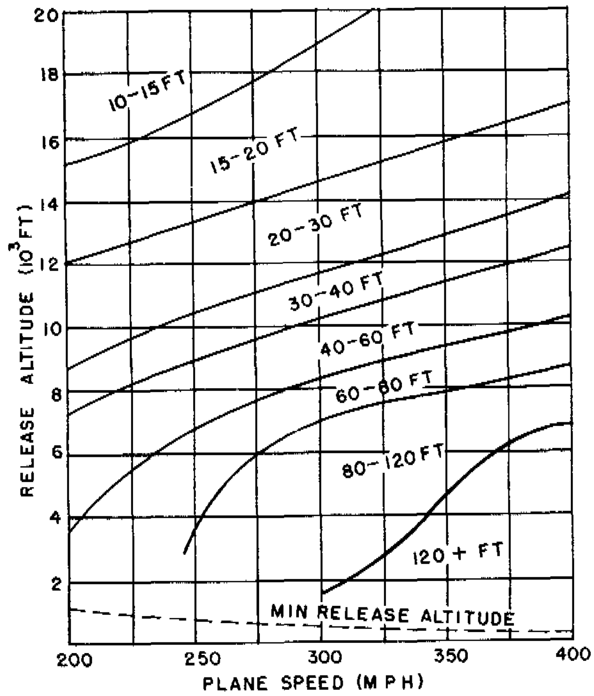

FIGURE 11. Iso-burst-height curves (predicted) for M-168 fuze on M-81 (260-lb) fragmentation bomb for reflection coefficient of 0.5.

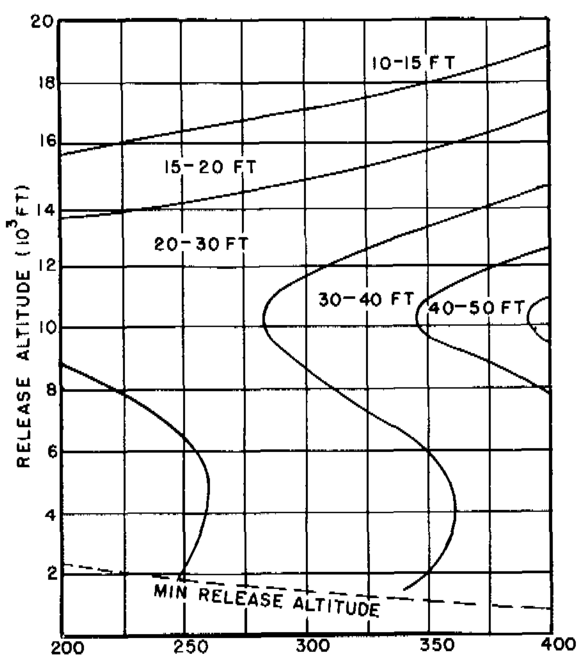

FIGURE 10. Iso-burst-height curves (predicted) for T-50-E1 or T-89 fuze on M-81 (260-lb) fragmentation bomb for reflection coefficient of 0.5.

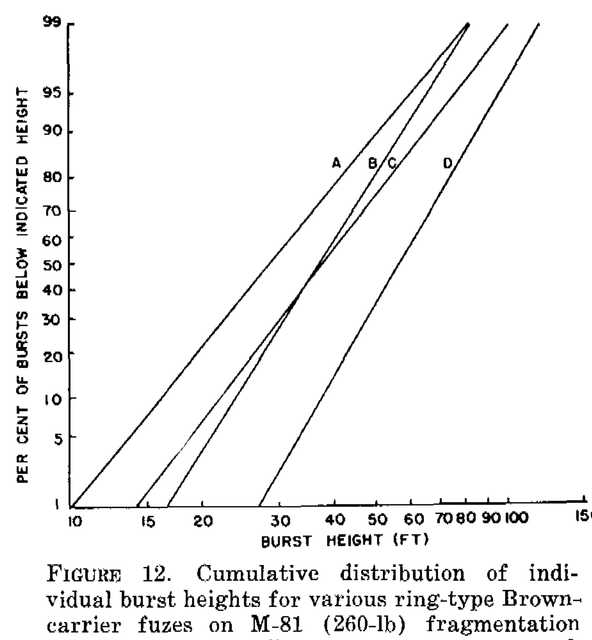

FIGURE 12. Cumulative distribution of individual burst heights for various ring-type Brown-carrier fuzes on M-81 (260-lb) fragmentation bomb. Reflection coefficient is 0.8 except as noted. A, T-50-E1 and T-89; B, Philco T-91, reflection coefficient 0.6; C, GE T-91; D, M-168, reflection coefficient 0.6, plane speed 240 mph.

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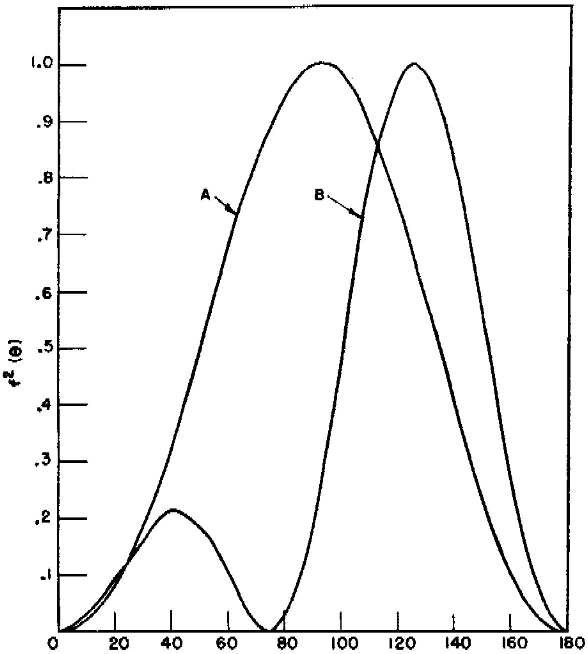

FIGURE 13. Radiation directivity pattern for Brown frequency longitudinal end excitation of bombs: A, M-30 or M-81 ($\frac{1}{2}\ \pi\beta = 0.124$); B, M-66 ($\frac{1}{2}\ \pi\beta = 0.207$).

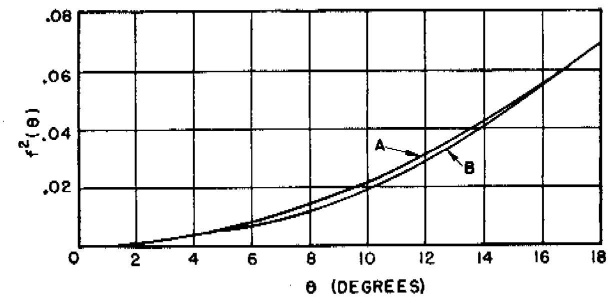

FIGURE 14. Small angle detail for M-30 pattern of Figure 13 for frequencies: A, B — 1; B, B + 5.5.

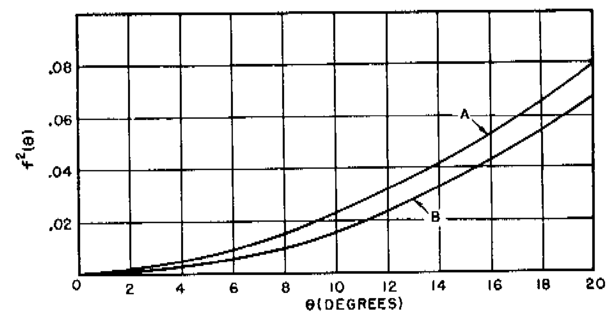

FIGURE 15. Small-angle detail for M-81 pattern of Figure 13 for frequencies: A, B + 0; B, B + 9.4.

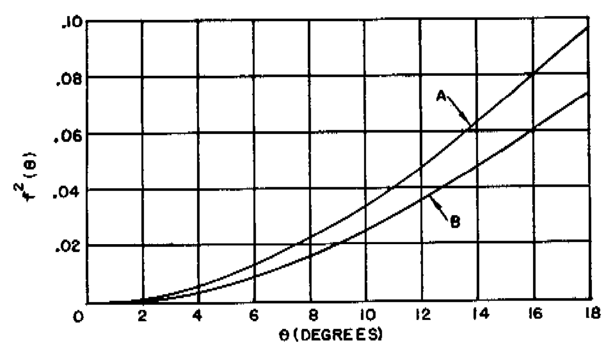

FIGURE 16. Small-angle detail for M-66 pattern of Figure 13 for frequencies: A, B + 5.5; B, B — 0.8.

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5.5.3

Bomb Fuzes, Ring Type, White Carrier

TABLE 13. Characteristics and scores.

	Level release		Dive release	
	T-90	T-50-E4	T-92	T-92-E1
Arming				
MinSAT (ft)	3,600	3,600	2,600	2,600
Safety pin	Yes	No	Yes	Yes
Delay device	Yes	Yes*	Yes	Yes
Rotor setting°	145	140	110	80
Rotor shaft	Closed	Closed	Closed	Open
Vane	3-blade Bakelite prop	.....	.....	.....
Vane lead (in.)	9	.....	.....	.....
Electrical				
Radio				
Circuit	OD	OD	OD	RGD
CF	+9.0	+9.3	+8.5	+5.6
S (volt)	19 (6.5)	18 (6.5)	18 (6.5)	30 (3.5)
Detuned (%)	5	5	4	.....
Audio				
Amp. No.	11	11	16	18
PkAF (c)	190	185	160	156
MvF (Pk)	27	30	22	21
CV (−volt)	7.4	7.4	7.4	7.6
EC (−volt)	4.6	4.6	4.6	4.0
Proof performance				
Burst height (ft)	39	39	33	40
Proper (%)	78	78	58	79
Random (%)	19	19	34	18
Dud (%)	3	3	8	3
Production				
Manufacturer	Emerson	.....	.....	.....
Quantity (MP lots)	50	80	44	6
AN/CPQ-	1B	1C	1A, 1B	1A, 1B
PA-	264	181	306	.....

* Not loaded with fuzes. Requires mounting bracket as on T-51.

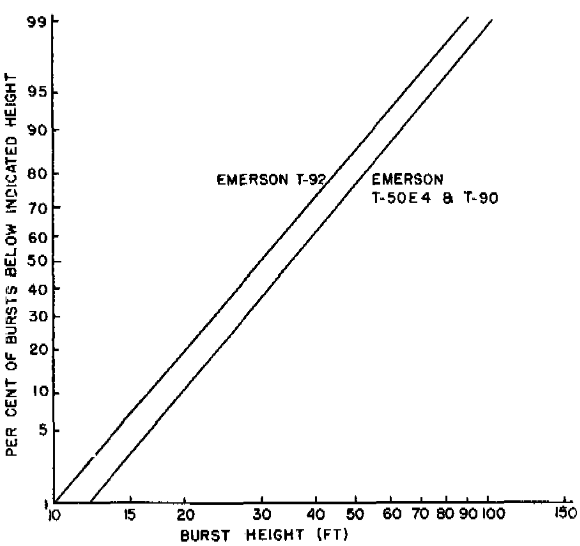

FIGURE 17. Cumulative distribution of individual burst heights for ring-type White-carrier fuzes on M-64 500-lb GP bomb. Reflection coefficient is 0.8.

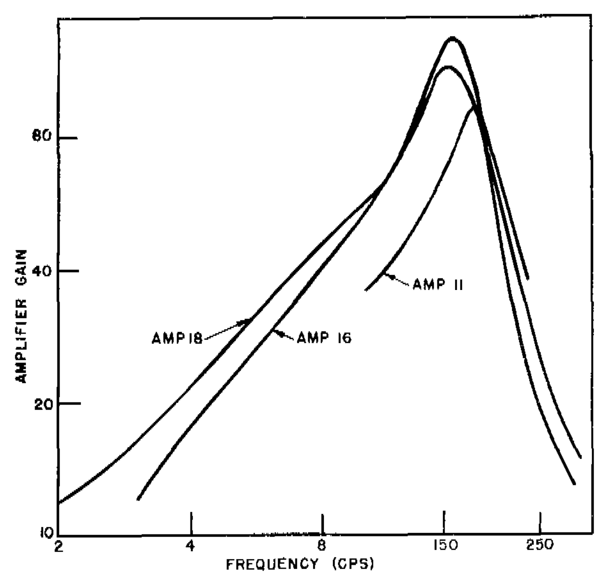

FIGURE 18. Amplifier gain as function of signal frequency for ring-type White-carrier bomb fuzes. Amp 11 in T-50-E4, Amp 16 in T-92, Amp 18 in T-92-E1.

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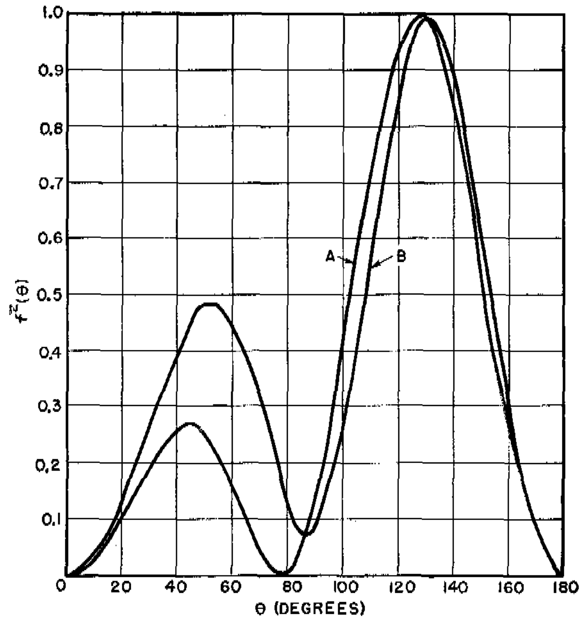

FIGURE 19. Radiation directivity patterns for White + 10 frequency longitudinal end excitation of bombs: A, M-64 ($\frac{1}{2}\ \pi\beta = 0.208$); B, M-65 ($\frac{1}{2}\ \pi\beta = 0.182$).

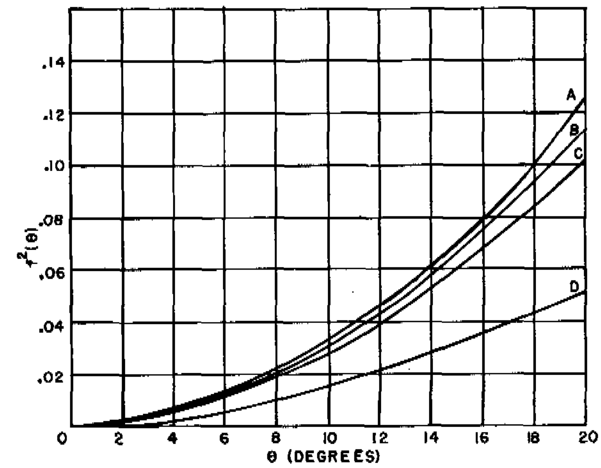

FIGURE 20. Small-angle detail for Figure 19: A, M-65 at W + 10; B, M-65 at W + 0.2; C, M-64 at W + 10; D, M-64 at W + 0.2.

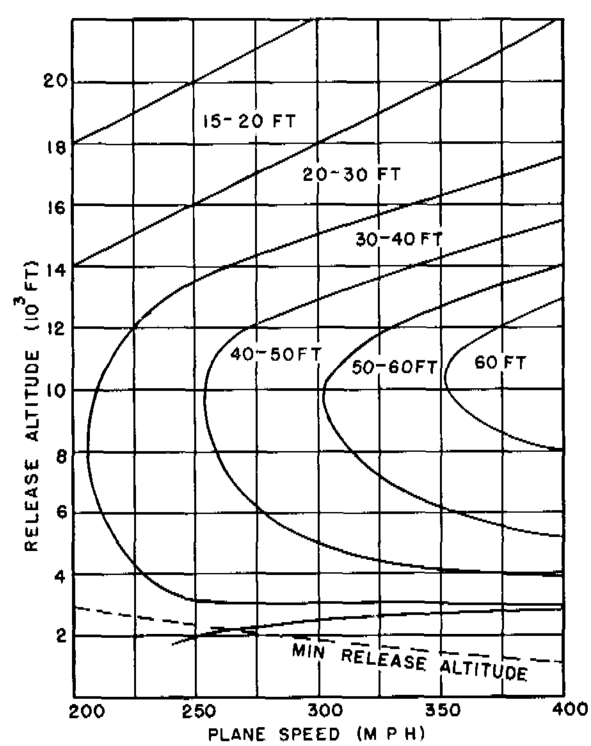

FIGURE 21. Iso-burst-height curves (predicted) for T-50-E4 or T-90 fuze on M-64 (500-lb) GP bomb for reflection coefficient of 0.5.

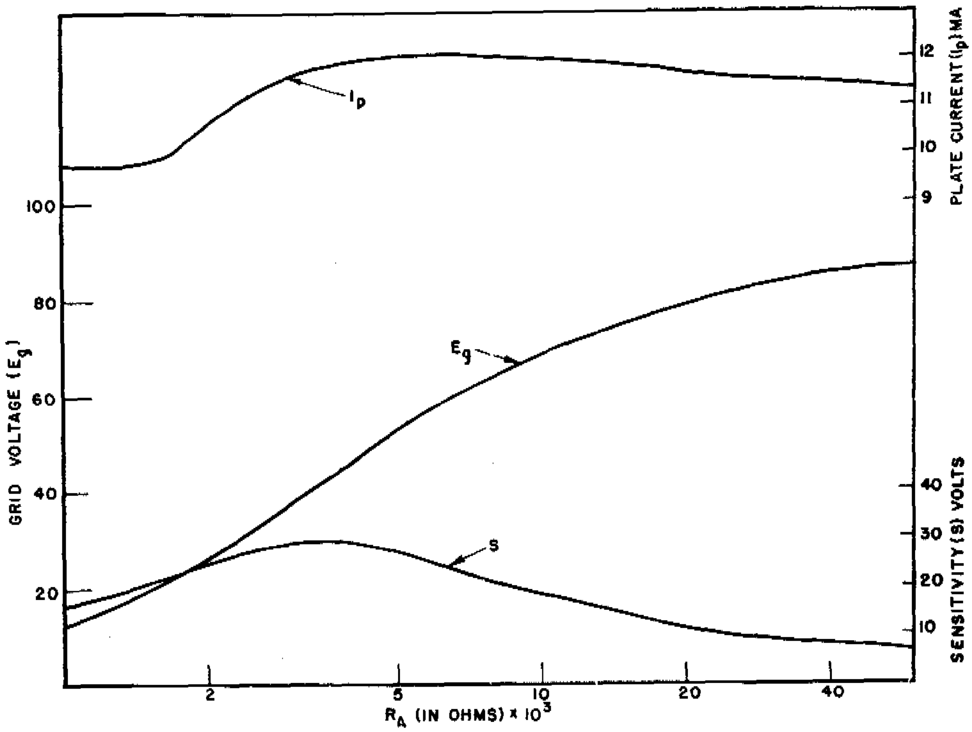

FIGURE 22. Oscillator loading characteristics of the T-92-E1 bomb fuze. Plate current I_p, grid voltage E_g, and radiation sensitivity S are shown as functions of radiation resistance R_a.

5.5.4

Bomb Fuzes, Bar Type, Yellow Carrier

TABLE 14. Characteristics and scores.

	Level or dive release M-166 (T-51-E1)		Special for M-56 GP T-712
Arming			
MinSAT (ft)	3,600	.....	.....
Safety pin	Yes	.....	.....
Delay device	Yes	.....	.....
Rotor setting (°)	153	.....	.....
Rotor shaft	Closed	.....	.....
Vane	3-blade Bakelite prop	.....	.....
Vane lead (in.)	6	.....	.....
Electrical			
Radio			
Circuit	RGD	.....	.....
CF	8.5	7.4	9.9
S (volt)	14	13	11
Audio			
Amp. No.	P5	.....	.....
MvF (165 c)	32	33	52
MvF (300 c)	42	46	74
EC (−volt)	3.7	3.8	3.6
CV (−volt)	7.9	7.8	7.8
Proof performance			
Burst height	110	110	50*
Proper (%)	91	85	100
Random (%)	9	15	0
Dud (%)	0	0	0
Production			
Manufacturer	Zenith	Emerson	Zenith
Quantity (MP lots)	230	24	2
AN/CPQ-	5C	.....	.....
PA-	283	283	.....

* Tested on M-81 (reflection coefficient, 0.6; speed: 240 mph).

[redacted]

Bomb weights and relative burst heights for M-166.

Bomb	Weight (lb)	Relative burst height	Bomb	Weight (lb)	Relative burst height
M-30	100	1.28	M-64	500	0.73
M-88	220	1.00	M-65	1,000	0.69
M-81	260	1.00	M-66	2,000	0.40
M-57	250	1.00	M-56	4,000	1.37

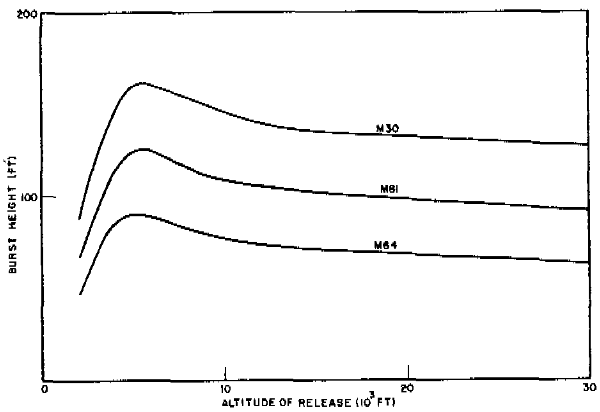

FIGURE 23. Burst height as function of altitude of release for Zenith T-51-E1 fuze on several bombs. Reflection coefficient is 0.8.

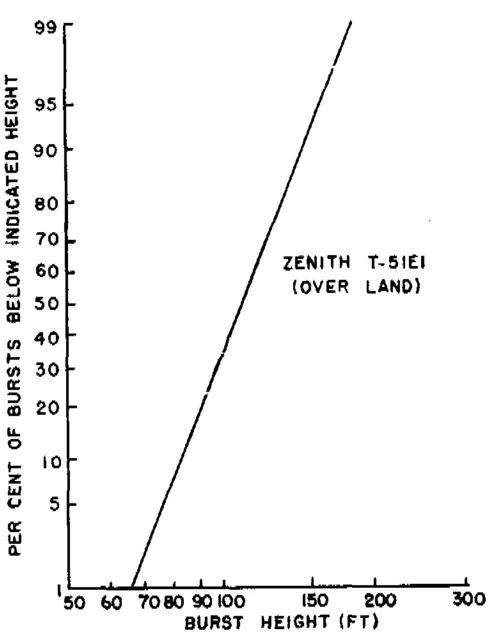

FIGURE 24. Cumulative distribution of individual burst heights for Zenith T-51-E1 fuze on M-81 (260-lb) fragmentation bomb. Reflection coefficient is 0.6.

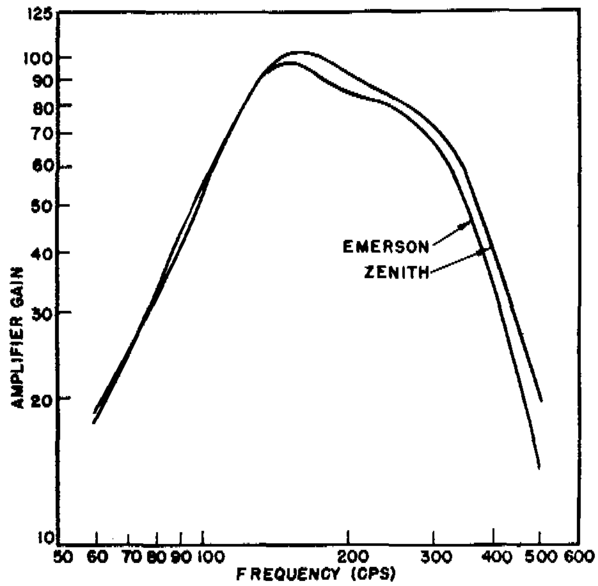

FIGURE 25. Amplifier gain as function of signal frequency for bar-type Yellow-carrier bomb fuzes.

5.5.5 Navy Rocket Fuze, Ring Type, Brown Carrier

TABLE 15. Characteristics and scores.

	Plane to Surface T-2004
Arming	
MinSAT (ft)	1,000
Safety pin	Yes
Vane	10-blade metal prop
Vane angle (°)	65
Electrical	
Radio	
Circuit	OD
CF	+1.3
S (volt)	15
Detuned (%)	2
Audio	
PkAF (c)	125
MvF (Pk)	109
CV (−volt)	7.7
EC (−volt)	4.1
Proof performance	
Burst height*	30
Reflection coefficient	0.81
Proper (%)	94
Random (%)	3
Dud (%)	3
Production	
Manufacturer	Philco
Quantity (MP lots)	75
MP designation	AN/CPQ-3A
PA-	315

* Fired from a ground launcher at approximately 30-degree elevation. External physical dimensions are same as those of ring-type bomb fuzes.

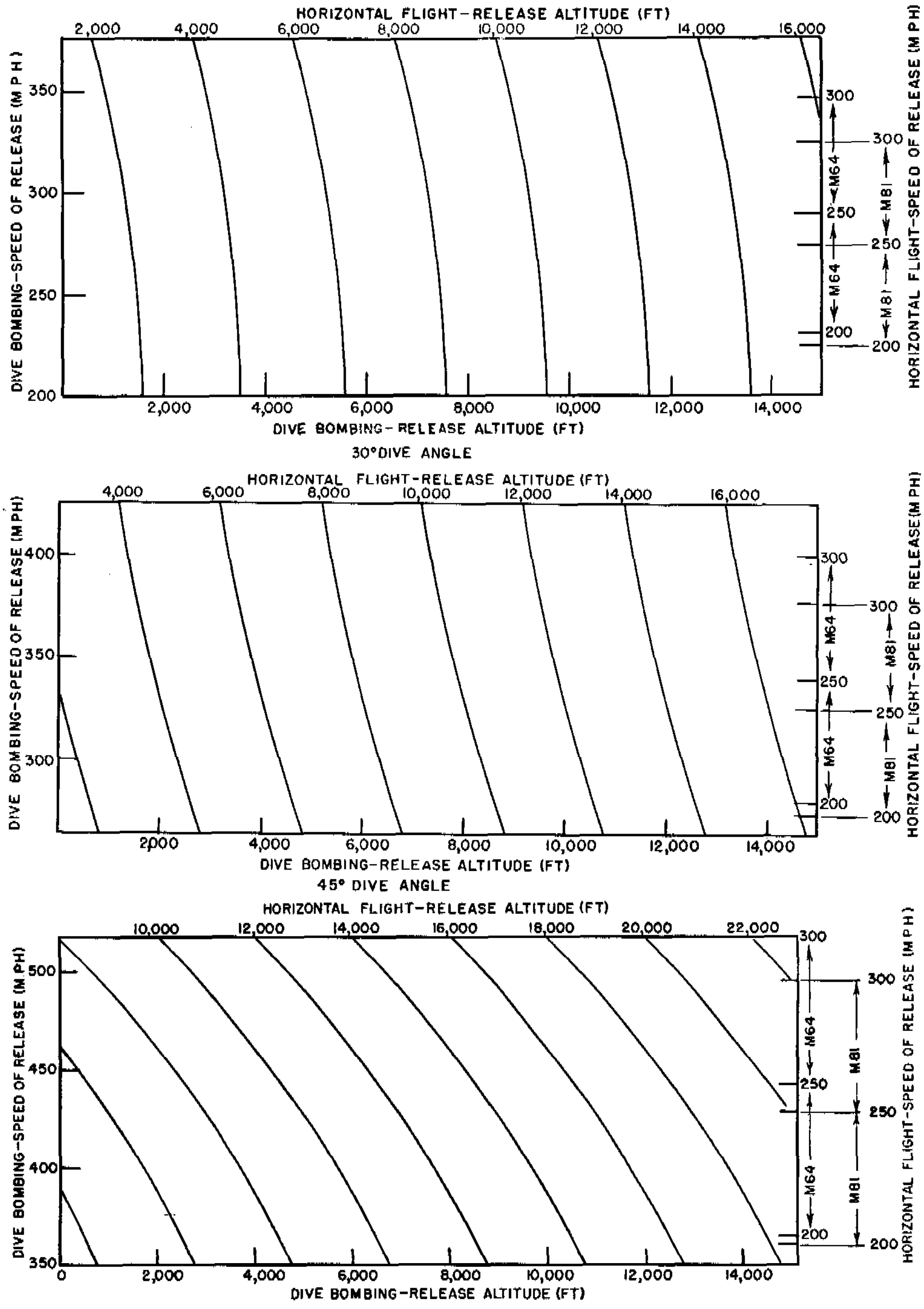

FIGURE 26. Equivalent altitude and plane speeds for level-flight and dive-bombing releases at dive angles of 30°, 45°, and 60°. Given burst height as function of level-flight release altitude and plane speed (see, for example, iso-burst-height curves), this chart may be used to determine burst height for dive-bombing releases. Scale for M-64 bomb may be used for larger bombs in GP series. Scale for M-81 bomb gives rough approximation for M-30.

[redacted]

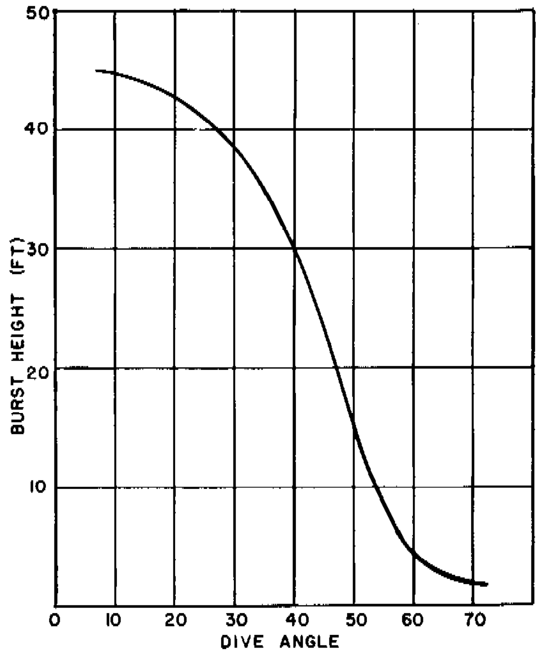

FIGURE 27. Burst height as function of dive angle for T-2004 fuze on 5.0-in. AR Navy rocket for firing at plane speed of 300 knots at range of 1,500 to 2,000 yd. (Fired over ground at Inyokern.)

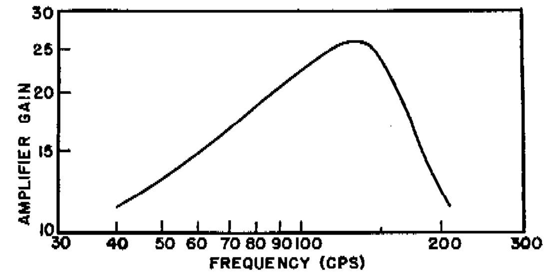

FIGURE 29. Amplifier gain as function of signal frequency for the T-2004 ring-type Brown-carrier Navy rocket fuze.

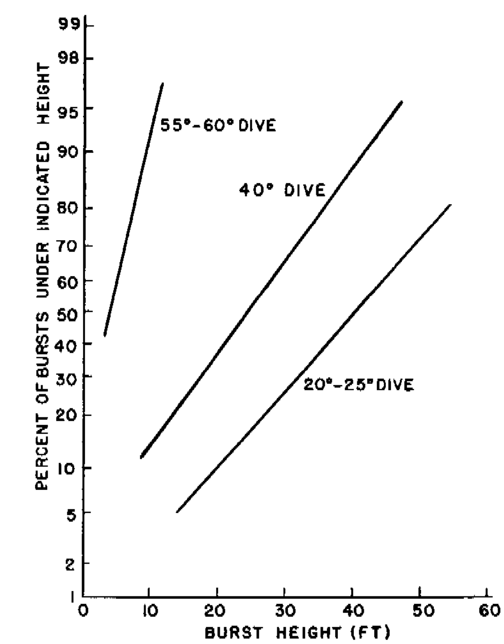

FIGURE 28. Cumulative distribution of individual burst heights for T-2004 fuze on 5.0-in. AR Navy rocket for firing at plane speed of 300 knots at range of 1,500 to 2,000 yd (Inyokern data).

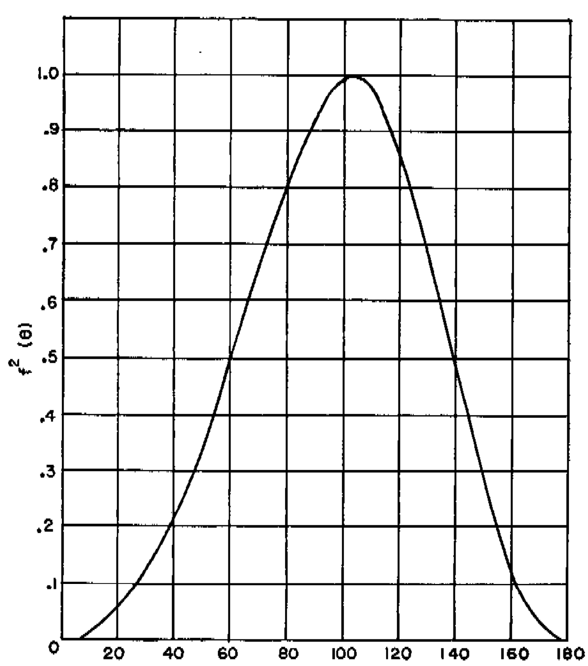

FIGURE 30. Radiation directivity pattern for Brown frequency longitudinal end excitation of 5.0-in. AR Navy rocket ($\frac{1}{2}\pi\beta = 0.130$).

5.5.6 Army Rocket Fuzes

TABLE 16. Characteristics and scores.

Type: longitudinally excited. Carrier: Red, Yellow, Green.
T-5: Plane-to-plane or plane-to-ground
T-6: Ground-to-ground

Arming: MinSAT (ft) T-5: 525
T-6: 2,400
Electrical (same for T-5 and T-6) Circuit: OD. Sensitivity (volt): 18.

	Test Voltages	
	A: 1.40 B: 135	A: 1.15 B: 115
PkAF (c)	121	
MvF (Pk)	37	51
Rel gain at 20 c (%)	18	22
Rel gain at 300 c (%)	19	25
SD time (sec)	8	

Proof performance

		T-6	
	T-5	Philco	Fricz
Proper (%)	81	84	72
Early (%)	13	..	..
Late or Mid (%)	2	12	24
Dud (%)	4	4	4

Weight and dimensions (same for T-5 and T-6)
Length (overall): $7\frac{9}{16}$ in. Length (outside rocket): $2\frac{5}{16}$ in.
Width (overall): $3\frac{3}{16}$ in. Weight (lb): $2\frac{3}{4}$
Physically interchangeable with contact fuze PD-M-4

Manufacturers	Emerson	Fricz	GE	Philco	Westinghouse	All
Quantity (MP lots)	100	25	80	110	80	395

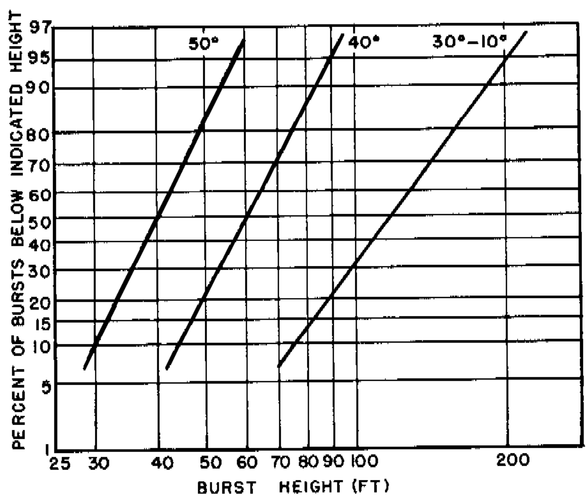

FIGURE 31. Cumulative distribution of individual burst heights for T-6 fuze on 4.5-in. Army rocket for several firing elevations as indicated. Reflection coefficient is 0.96.

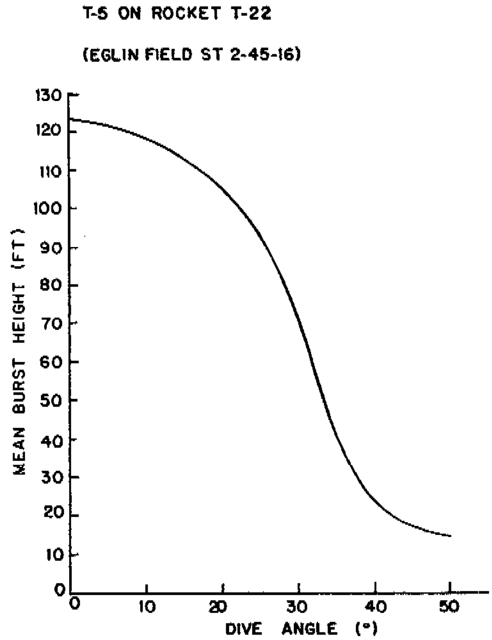

FIGURE 32. Burst height as function of dive angle for T-5 fuze on T-22 Army rocket for firing at plane speed of approximately 300 mph at range 700 to 1,000 yd. (Fired over ground at Eglin Field.)

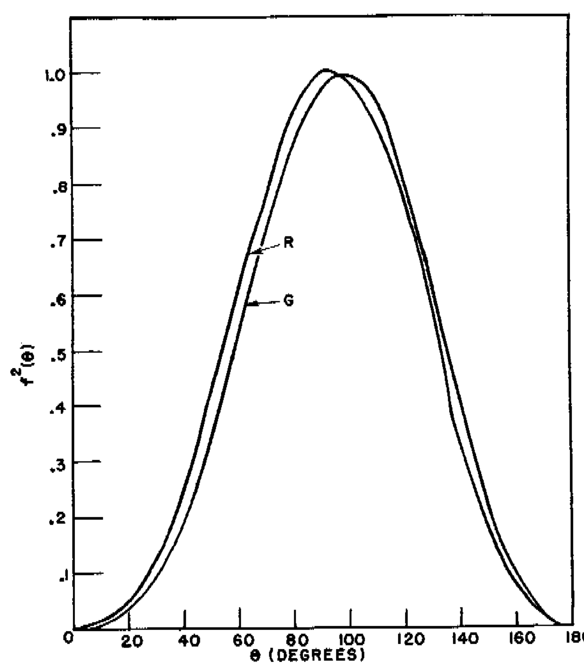

FIGURE 33. Radiation directivity pattern for Red and Green frequency longitudinal end excitation of 4.5-in. Army rocket.

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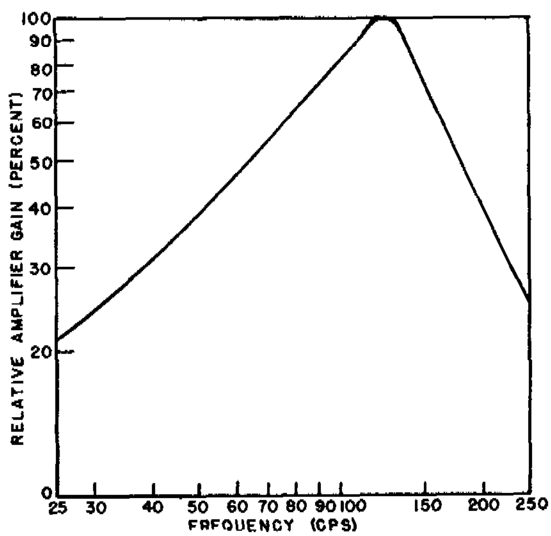

FIGURE 34. Amplifier gain as function of signal frequency for the T-5 or T-6 Army rocket fuze.

5.6 PREPRODUCTION FUZES

The VT fuzes which were not in production at the end of World War II are covered in this section. They were as follows:

Vehicle	Fuze	Type	Frequency
Bomb	T-82	Bar	White
Navy rocket	T-30	Ring	Brown
	T-2005	Longitudinally excited	Brown
Mortar shell	T-132	Longitudinally excited	White
	T-171	Longitudinally excited	Brown
	T-172	Transversely excited	Yellow

5.6.1 Bomb Fuze T-82, Bar Type, White Frequency

The bomb fuze T-82 was designed for the same purposes as the M-166 (T-51-E1). When it was found that the M-166 would meet military requirements adequately and could be produced in quantity with a minimum of new tooling, the need for the T-82 diminished and it did not reach the production stage until just before the end of World War II. The data given here were obtained from pilot-production samples and from the mass-production type-approval sample.

The T-82 featured a turbine-driven generator mounted in the base of the fuze. An air intake port was provided through the center of the fuze; there were two exit ports on opposite sides of the fuze near the base (see Figure 28 of Chapter 4). The design had several advantages over that of the other bomb fuzes. The location of all moving parts close to the supporting base, and well removed from those sections of the electric circuit that are most susceptible to mechanical disturbances, aided in the production of a very stable fuze. On the other hand, it was found that the variations in turbine speed were somewhat greater than the variations in propeller speed of the other bomb fuzes. This appeared both as a greater spread in air travel to arming of individual fuzes under a given release condition and as a greater dependence of air travel on bomb size.

Relative air travel on various bombs

M-30	M-81	M-64	M-65	M-66	M-56
1.00	1.02	1.24	1.48	2.32	1.87

Two models, the T-82-E1 set for 3,600 ft MinSAT (not equipped with the arming delay bracket) and the T-82-E2 set for 2,000 ft MinSAT (equipped for arming delay device) were current at the end of World War II. The following data may be taken as representative of the principal characteristics of both models.

The mechanical design of the T-82 is described in Chapter 4; its principal components

TABLE 17. Pertinent features of T-82.

Electrical	
Radio	
Circuit	POD
CF	+16.7
$S\left(\frac{\Delta I_p}{I_p \text{ for } R = \infty} 100\right)$	12
Audio	
PkAF	184
MvF (Pk)	29
MvF (140)	37
MvF (280)	48
CV (−volt)	7.7
EC (−volt)	3.4 (20 to 35K)
Proof performance*	
Burst height	101
Reflection coefficient	0.8
Proper (%)	83
Random (%)	11
Dud (%)	6
Physical characteristics	
Overall length (in.)	8
Length from shoulder (in.)	3
Overall width (in.)	10
Weight (lb)	3$\frac{3}{5}$
Manufacturer: Westinghouse	

* From 10,000 ft at 200 mph on M-81 or M-88.

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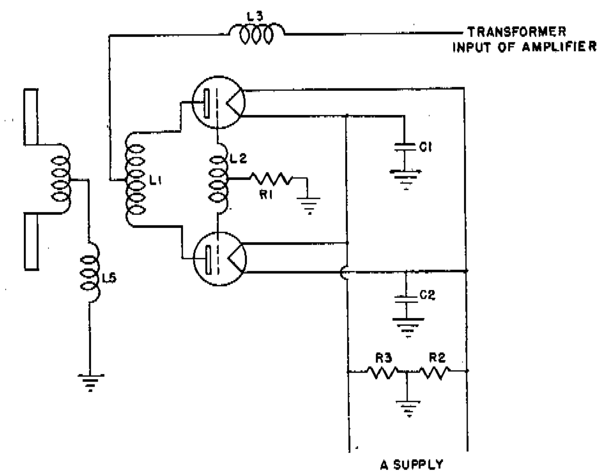


FIGURE 35. Power-oscillating-detector circuit used in T-82 bar-type White-carrier bomb fuze.

are shown in Figure 28 of the same chapter. The arming mechanism has to be built more compactly than in the other bomb fuzes on account of the lower position of the generator; otherwise it is essentially the same.

The power oscillating detector used in the T-82 is shown in Figure 35. The component values given in Table 18 are for the T-82-E2, as required by Army Ordnance specification[14] prepared in collaboration with Division 4.

TABLE 18. Component values of POD oscillator in T-82 fuze.

Resistor	Value (ohms)	Con-denser	Value ($\mu\mu$f)	Coils	Turns
R1	100,000	C1	500	1	9 (antenna)
R2	6.8	C2	500		6 (plates)
					(wound on same form)
R3	6.8			2	12
				3	90
				5	90
		Triodes: NR3A			

The nearly symmetrical oscillator assembly (on a phenolic block) is shown in Figure 28, Chapter 4. The two triodes are located on opposite sides of the central air duct, in line with the dipole bars. On a line at right angles are the interwound plate and antenna coils (top) and grid coil (bottom). The remaining oscillator components are disposed in a symmetrical fashion with respect to these.

The basic amplifier circuit of the T-82 bar-type bomb fuze is shown in Figure 32, Chapter 3. The component values given in Table 19 are for the T-82-E2, as required by Army Ordnance specification,[14] prepared in collaboration with Division 4.

TABLE 19. Component values for amplifier in T-82-E2 fuze.

Resistor	Value (megohms)	Condenser	Value ($\mu\mu$f)
R5	2.2	C3	10,000
R6	0.3	C4	50
R7	115 ohms	C5	50
R8	3.3	C6	50
R9	3.3	C7	50
R10	4.7	C8	50
R11	1.0	C9	0.1 μf
R12	1.0	C10	10,000
		C11	1,000
R14	330 ohms	C13	0.6 μf
R15	1.0	C14	0.2 μf
R16	1.0		
R17	30,000 ohms		
R18	3,000 ohms		
	Pentode: NS5		

Notes. For R20, see R2 and R3 in oscillator circuit for the T-82.

A gain-control condenser C_g shown in Figure 16, Chapter 3, is not present in the T-82 circuit, the gain of which may be adjusted by selection of suitable value for C11.

The transformer secondary is shunted by C3 and R6 in parallel instead of in series, as appears in Figure 16, Chapter 3.

The general character of the amplifier assembly of the T-82 differs somewhat from that of the other bomb fuzes on account of space requirements of the central air duct. The assembly and its major parts are shown in Figure 13, Chapter 6.

5.6.2 Navy Rocket Fuzes

T-30 (MK 171, MOD O) RING TYPE, BROWN CARRIER

The fuze T-30, like the T-2004, was a bomb fuze modified for use on a Navy airborne rocket. The T-30 was intended primarily for attacking enemy aircraft with the HVAR. The weakness of enemy opposition in the air during the later stages of World War II made its production less urgent than that of some of the other fuzes. Although mass production (by General Electric) had barely started when World War II ended, considerable testing was done with the pilot production model (including a service test at the Naval Ordnance Test Station, Inyokern) and its properties were fairly well defined.

[redacted]

Early functioning of the T-30 on account of the considerable afterburning of the HVAR propellant was a serious problem. The expedient of delaying arming until afterburning was negligible and unsatisfactory because it gave an undesirably large minimum firing range. A program of research directed toward the elimination of afterburning was partially successful, but the problem was by no means completely solved at the end of World War II.

There was no fixed target testing with the HVAR. Consequently, the data presented in Table 20 for performance on this vehicle are limited to high-angle firing tests.

TABLE 20. Pertinent features of T-30.

Electrical*		
Radio		
Circuit	OD	
CF	+1	
S (volt)	18	
Audio		
PkAF (c)	69	
MvF (Pk)	24	
CV (−volt)	7.8	
EC (−volt)	3.9	
Proof performance†		
ROA (ft)	90	Vehicle: HVAR
Proper + Mid (%)	77	QE: 55°
Early (%)	20	
Dud (%)	3	
Physical and arming characteristics (same as T-2004)		
Overall length (in.)	$10\frac{1}{32}$	
Length from shoulder (in.)	$4\frac{15}{16}$	
Overall width (in.)	$3\frac{3}{8}$	
Weight (lb)	4	

* From General Electric units.
† Bowen units; no data available on GE.

The structure of the T-30 is practically the same as that of the T-2004 and the OD-circuit ring-type bomb fuzes and therefore requires no additional description.

T-2005

The T-2005 was the logical next step after the T-2004 and T-30: a GP rocket fuze of small size making use of the designs being developed for mortar shell fuzes and provided with an external switch to permit selection in the field between two sets of characteristics appropriate to plane-to-plane or plane-to-surface firing. Test data are very scanty, and the characteristics of this fuze can be represented best by the tentative specifications that were completed immediately before the end of World War II. Some of the specification requirements are shown in Table 21. The fuze is shown in Figure 46 of Chapter 4.

TABLE 21. Pertinent features of T-2005.

	Plane-to-Plane	Plane-to-Surface
Vane	Turbine	Same
Electrical		
Radio		
Circuit	RGD	Same
CF	−2 to −8	Same
S (volt)	>10 from 2K to 20K ohms	Same
Audio		
PkAF	60 to 100	100 to 160
MvF (Pk)	15 to 30	70 to 130
MvF (75c)	....	115 to 105
CV (−volt)	6.8 to 8.5	Same
EC (−volt)	5.0 max (15K to 50K rpm)	Same
Physical characteristics		
Overall length	$4\frac{5}{8}$ in.	
Length from shoulder	$4\frac{3}{8}$ in.	
Overall width	$2\frac{1}{2}$ in.	
Weight	28 oz	

The general design of the T-2005 (Figure 46, Chapter 4) is similar to that of the T-171. Since the ballistic effect of this fuze is less important than that of the mortar shell fuzes, the antenna insulator is enlarged for increased strength. The safety and arming requirements placed on this fuze were rather complex, involving a number of users' options. The mechanism that was designed to meet these requirements is not readily described; reference is made to Figure 47 and the accompanying text in Chapter 4.

The electric circuit diagram of the T-2005 is shown in Figure 36.

5.6.3 Mortar Shell Fuzes

T-132, Longitudinally Excited, White Frequency
T-171, Longitudinally Excited, Brown Frequency
T-172, Transversely Excited, Yellow Frequency

All the mortar shell fuzes were considerably smaller than the rocket and bomb fuzes. In spite of this reduction in size, it was necessary to use the larger tail of the M-56 shell when they were mounted on the small M-43 mortar shell in order to obtain stable flight. They were designed primarily for use on 81-mm shells such as the M-43 and the M-56.

The T-132 featured a radical innovation in electric construction: the production of a con-

siderable part of the electric circuit by painting conducting material onto a ceramic base (see Chapter 6). This technique was designed to facilitate the maximum possible rate of production.

Since immediate success of the new technique could not be assured, the T-171 was developed simultaneously, using standard components.

Another innovation was the loop antenna, featured in the T-172.

The three fuzes are shown in Figure 6, Chapter 1, and Figures 42, 43, and 44, Chapter 4. Except for the items mentioned above, they were quite similar in design.

None had entered mass production at the close of World War II. Preparations for mass production of the T-132 had been completed. Considerable pilot production and developmental testing data are available for this fuze. Developmental testing data alone are available for the T-171 and T-172. Some use is made of specification requirements and design data in representing the laboratory characteristics of the latter two fuzes.

The field performance scores for the mortar shell fuzes are of necessity averages over periods involving a number of design changes. Although the scores are not impressive, they compare favorably with those obtained with

TABLE 22. Pertinent features of T-132 (Globe-Union).

Arming (yd)	300 (approx)
Vane	Turbine
Electrical	
Radio	
Circuit	RGD
CF	+11.6
S (volt)	(11 at 6,000 ohms)
	(9 at 20,000 ohms)
Audio	
PkAF	107
MvF (Pk)	44
MvF (40)	84
CV (−volt)	7.5
EC (−volt)	5.0 max*
	6.0 max†
Proof performance‡	
Burst height (ft) (over water)	8
Proper (%)	68
Random (%)	16
Dud (%)	17
Physical characteristics	
Overall length	$4\frac{7}{8}$ in.
Length from shoulder	$3\frac{3}{4}$ in.
Overall width	2 in.
Weight	22 oz

* On raising generator speed from 20,000 to 80,000 rpm.
† On lowering generator speed from 80,000 to 0 rpm.
‡ On M-43 with M-56 tail charge: 1-4. QE: 45° to 80°.

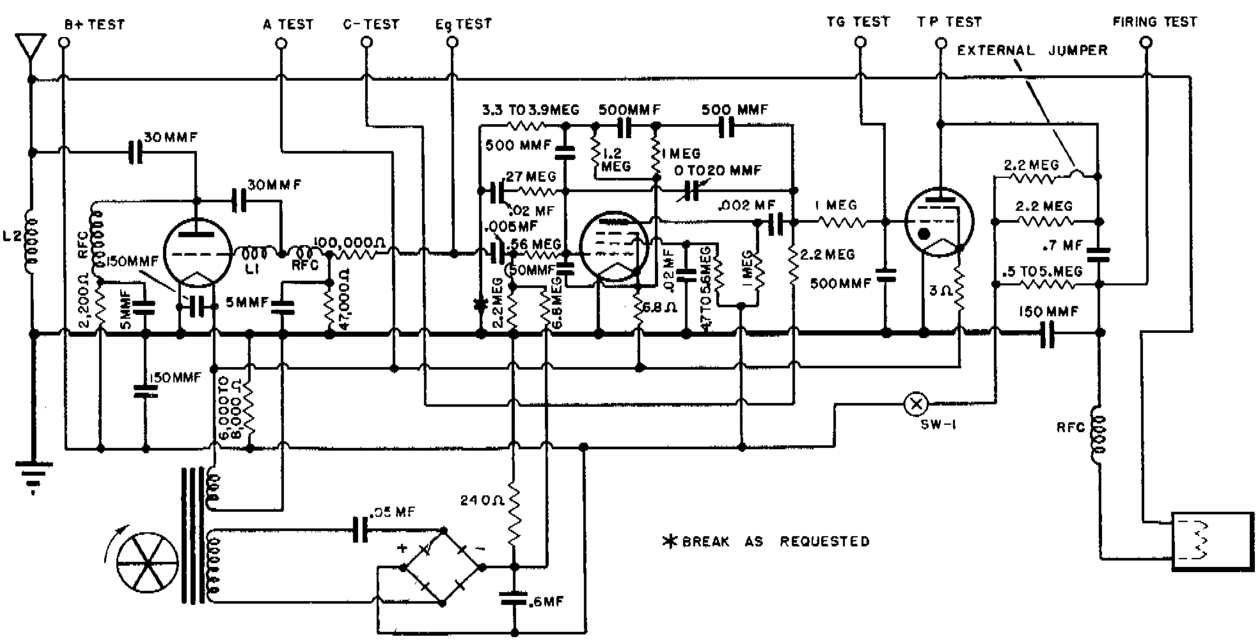


FIGURE 36. Electric circuit of T-2005 rocket fuze.

[redacted]

rocket and bomb fuzes at the same stage of development. Pertinent features are shown in Tables 22, 23, and 24. See Chapter 4 for further structural details of the mortar shell fuzes.

The latest circuits of the mortar shell fuzes are shown, with component values entered thereon, in Figures 37, 38, and 39. The circuits for the T-132 and T-171 are taken from Army Ordnance specifications,[15, 16] prepared in collaboration with Globe-Union, Inc., National Bureau of Standards, and Division 4. The T-172 circuit is taken from the final progress report of the Zenith Radio Corporation on this project.

The ceramic oscillator block of the T-132 in various stages of "painting" of components and

TABLE 23. Pertinent features of T-171 (NBS).

Arming (yd)	300 (approx)
Vane	Turbine
Electrical	
Radio	
Circuit	RGD
CF	−5 to +5
S (volt)	4 min (60 and 90K)
Audio	
PkAF	80 to 120
MvF (Pk)	25 to 50
MvF (40)	60 to 140
CV (−volt)	6.6 to 8.7
EC	5.0 max*
	6.0 max†
Proof performance‡	
Burst height (ft) (over water)	19
Proper (%)	67
Random (%)	13
Dud (%)	20
Physical characteristics	
Overall length	$4\frac{7}{8}$ in.
Length from shoulder	$3\frac{3}{4}$ in.
Overall width	2 in.
Weight	22 oz

* On raising generator speed from 15,000 to 60,000 rpm.
† On lowering generator speed from 60,000 to 0 rpm.
‡ On M-43 with M-56 tail charge: 2 and 4. QE: 45°.

TABLE 24. Pertinent features of T-172 (Zenith).

MinSAT (ft)	800
Vane	Turbine
Electrical	
Radio	
Circuit	RGD
CF	+11
S (volt)	3
Audio	
PkAF	95
Gain	75
Proof performance*	
Burst height (ft) (over water)	23
Proper (%)	48
Random (%)	27
Dud (%)	25
Physical characteristics	
Overall length	$6\frac{1}{2}$ in.
Length from shoulder	$5\frac{1}{2}$ in.
Overall width of body	2 in.
Diameter of loop	3 in.
Weight	24 oz

* On M-43 with M-56 tail charge: 2, 3, 4. QE: 45° to 80°.

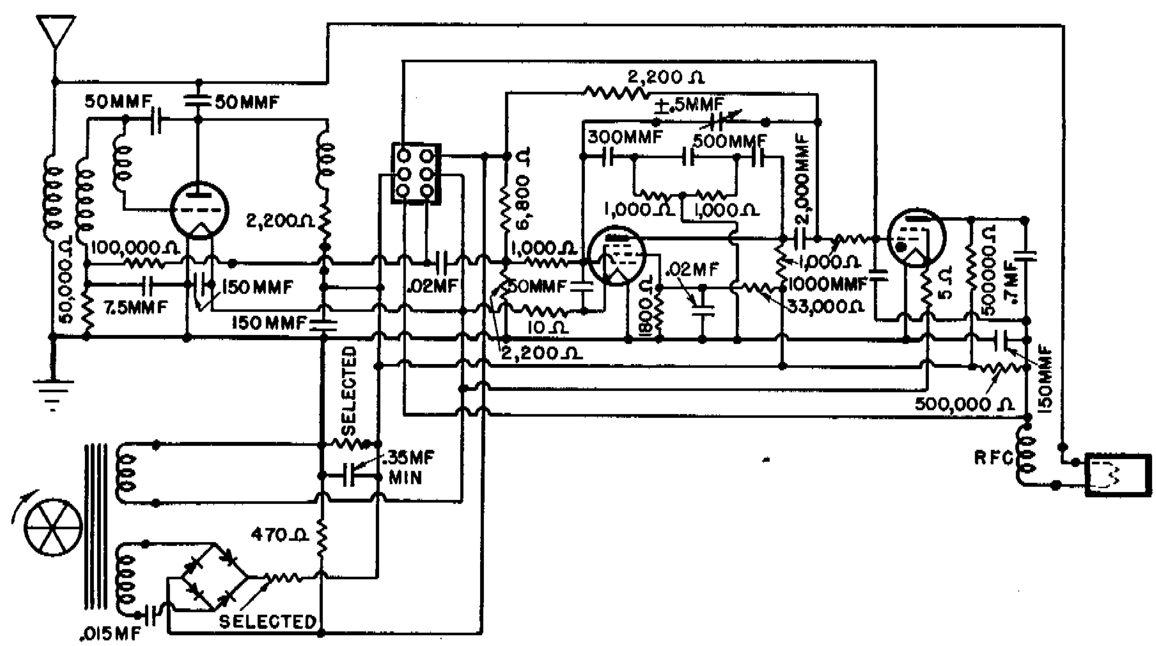


FIGURE 37. Electric circuit of T-132 mortar shell fuze.

[redacted]

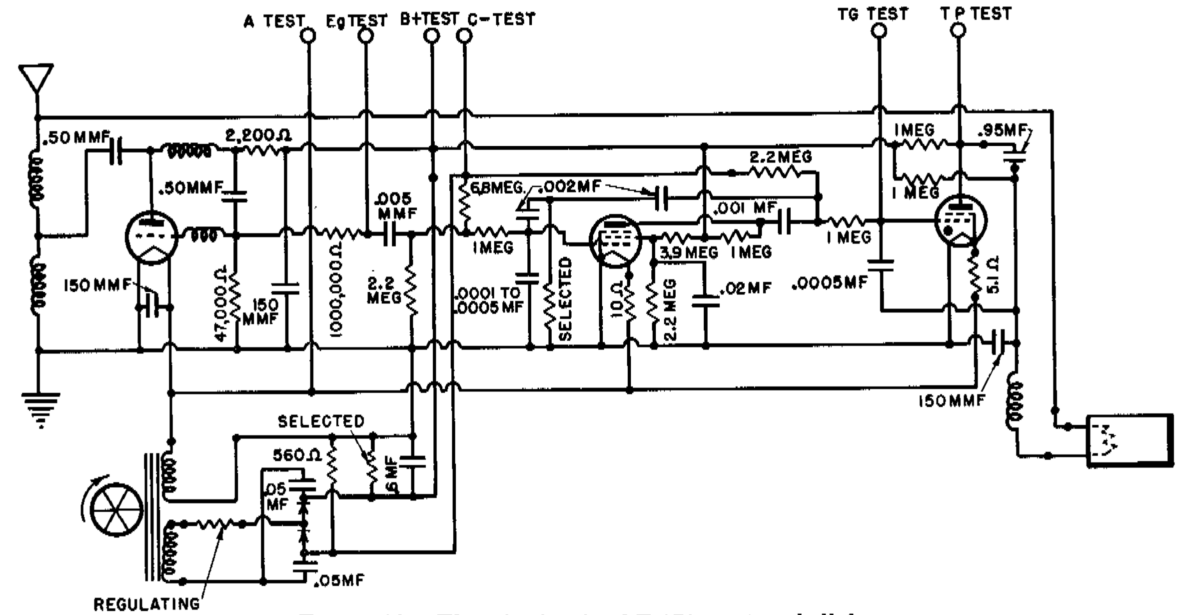


FIGURE 38. Electric circuit of T-171 mortar shell fuze.

the non-painted components and the complete assembly appear in Figures 10 and 7, Chapter 6. In the latter figure, the triode is seen to be located in the center, in the position occupied by the generator shaft in earlier fuzes; the small white disks are the condensers.

The latest model of the T-132 amplifier is shown in Figure 16, Chapter 6. The ceramic plate is mounted parallel to the longitudinal axis of the fuze. The figure shows both sides of the plate, in both the "painted" state and in the complete state. The reduction in size of this assembly, relative to that of the earlier fuzes, may be judged by comparing Figures 16 and 17, Chapter 6, noting that the electron tubes are the same in both cases.

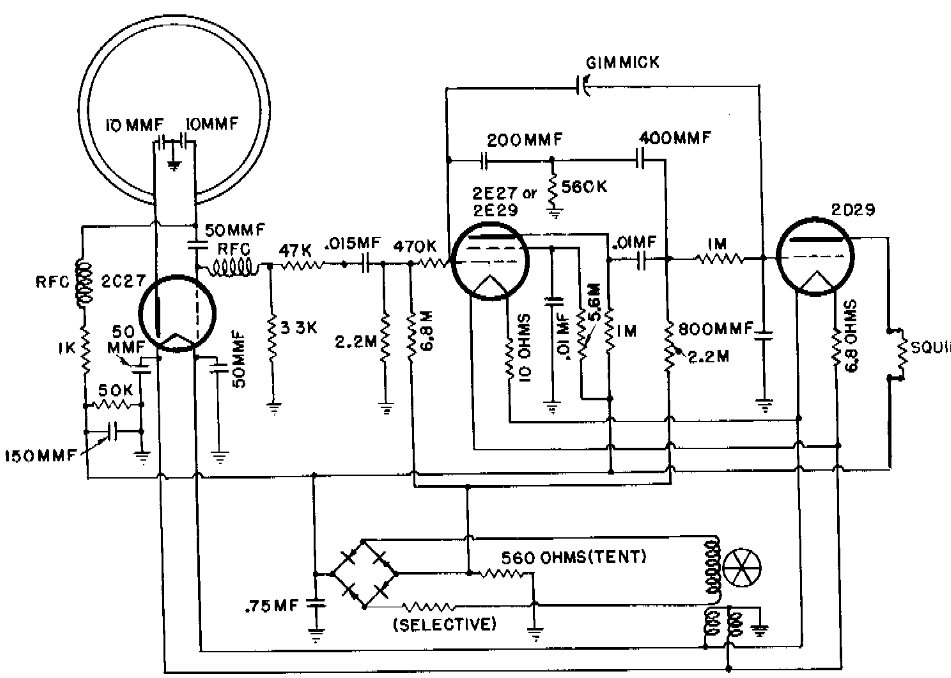


FIGURE 39. Electric circuit of T-172 mortar shell fuze.

[redacted]

Chapter 6

PRODUCTION[a]

6.1 INTRODUCTION

In the early days of radio proximity fuze development, many workers in the field were fearful that even though satisfactory models might be built in the laboratory by skilled people, the project would prove infeasible because those models could not be mass-produced successfully by unskilled labor in the huge quantities needed by the Services. Those who later encountered and overcame some of the production headaches that arose were, if the truth were known, often of the same opinion. The successive problems that arose were resolved by the skill, perseverance, ingenuity, and optimism of the technical and production staffs of the various manufacturers working in closest cooperation with physicists and engineers of the development staff.

It is the purpose of this chapter to outline briefly some of the production procedures that were adopted, some of the problems that arose and their resolution, and, in general, to point out some of the considerations involved in the quantity production of generator-powered proximity fuzes. No attempt will be made to go into great detail regarding the manufacture of any one type of fuze. Each type naturally has its own peculiar production problems.

6.1.1 Pilot Plant Production

An effort was made to anticipate and overcome the difficulties likely to be encountered in mass production by means of pilot production of considerable quantities of each type of fuze in plants set up for that particular purpose. These plants produced varying quantities of preproduction models, in some cases as many as 25,000 of a given type. The conditions under which these pilot plants operated were, to a considerable degree, the same as would be encountered in large-scale production. The labor was unskilled, or at best semiskilled; production-line techniques were employed; and the fuzes were not babied or hand-fitted at any stage of manufacture.

These pilot lines served several important functions in addition to developing production procedures and establishing an index of production feasibility and quality for the design. They served as a source of fuzes necessary for the extensive field testing of new designs, and they provided a flexible source of supply for fuzes modified from time to time as design changes were dictated by field test results, changes in tactical requirements, and by improvements by the design group.

6.1.2 Production Organization

To a first approximation, an organization for mass production of proximity fuzes bears a very close resemblance to the setup usually employed for mass production of radio receivers. They are similar in that both organizations (1) employ relatively unskilled labor, (2) break down production into a multiplicity of simple easily performed operations that can be quickly taught to such labor, (3) make use to the fullest possible extent of continuous production-line methods, and (4) employ similar tools and processes. The two organizations differ in that in the fuze plant (1) more frequent and more vigilant inspection is required, (2) closer liaison is required between engineering and production departments, (3) more frequent testing with more elaborate equipment is required, (4) production supervisors should be of a higher caliber since the emphasis must be on quality of production rather than, primarily, on quantity, and (5) eternal vigilance regarding small and, in some other products, unimportant details must be the rule.

[a] This chapter was prepared by A. S. Clarke of the Clarke Instrument Corporation, Silver Spring, Maryland, and consultant to the Ordnance Development Division of the National Bureau of Standards. Early in World War II, he was technical aide to Division 4, NDRC, and later manager of the Electronics Division, Bowen & Company, Bethesda, Maryland, engaged in pilot production of proximity fuzes.

If there is any formula for the successful production of radio proximity fuzes, it would probably read like this: Mix together equal parts of careful workmanship, rigid inspection, intelligent and responsible supervision, and good production designs.

A process flow chart showing the routing of fuzes through a typical plant is given in Figure 1.

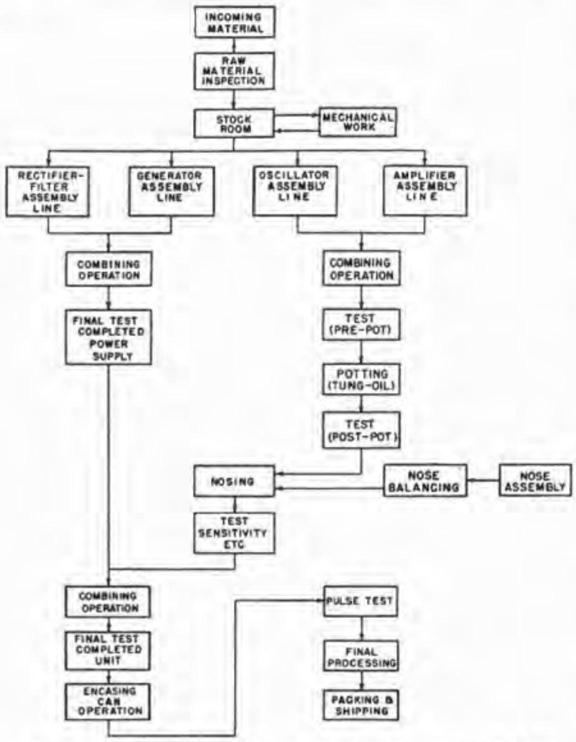


FIGURE 1. Process chart for production of T-51 fuzes, Zenith Radio Corporation (reference 17, Figure 3).

Typical interior views of plants engaged in mass production of fuzes are given in Figures 2 and 3.

A typical plant layout is shown in Figure 4.

6.1.3 Preproduction Planning and Preparation

One consideration that is fully appreciated by every production man but often discounted by design and laboratory workers is the necessity for a truly tremendous amount of planning and preparation for quantity production of even the simplest item. And the proximity fuze is no simple item. The whole process of mass production is a carefully integrated and very delicate mechanism with its various parts so interrelated and interdependent that a breakdown at any one point can throw the

FIGURE 2. View of production line for T-50 fuze at Emerson Radio and Phonograph Corporation (Emerson photograph).

whole plant into complete disorder. Before production justifying the name can begin, the following must be done: (1) all drawings must be completed, checked, and approved; (2) all tooling, including production jigs and fixtures,

FIGURE 3. Another view of production line for T-50 fuze at Emerson Radio and Phonograph Corporation (Emerson photograph).

must have been fabricated and checked; (3) all test equipment must be completed, tested, and installed; (4) supervisors must be trained; (5) inspectors and test equipment operators

must be trained; and (6) an adequate supply of *every* component or purchased subassembly must be on hand to support a continuous flow of production.

Of course there were occasions when, because of the pressure of wartime urgencies, production was started in advance of complete preparation as outlined above and some of the production difficulties that arose are directly traceable to this situation.

6.2 OSCILLATOR

6.2.1 Introduction

The design of the oscillator portion of various types of fuzes has been covered in considerable detail in previous sections of this report. No attempt will be made here to repeat this descriptive material, and it is presumed that the reader has studied and become familiar with it. The purpose of this chapter is to outline some of the procedures adopted in mass manufacture to insure that the requirements for a satisfactory oscillator portion of the fuze are fully met.

THE PROBLEM

Basically, the problem is to mass-produce a high-frequency oscillator of relatively small size that will (1) feed adequate energy to a suitable radiating system, (2) have the requisite frequency stability, (3) maintain the carrier frequency constant or within specified limits from fuze to fuze, (4) give uniform output from fuze to fuze, (5) be mechanically rugged to withstand the shocks incident to service, and (6) generate in itself no spurious responses that might result in premature fuze detonation.

All parts of the oscillator circuit of the fuze are in strong r-f fields. Any motion of these parts, either in relation to each other or to the chassis, will produce a signal on the grid of the amplifier tube that is indistinguishable from the signal from the selected target that initiates normal functioning. For this reason, every effort must be made in production to produce a rigid r-f assembly.

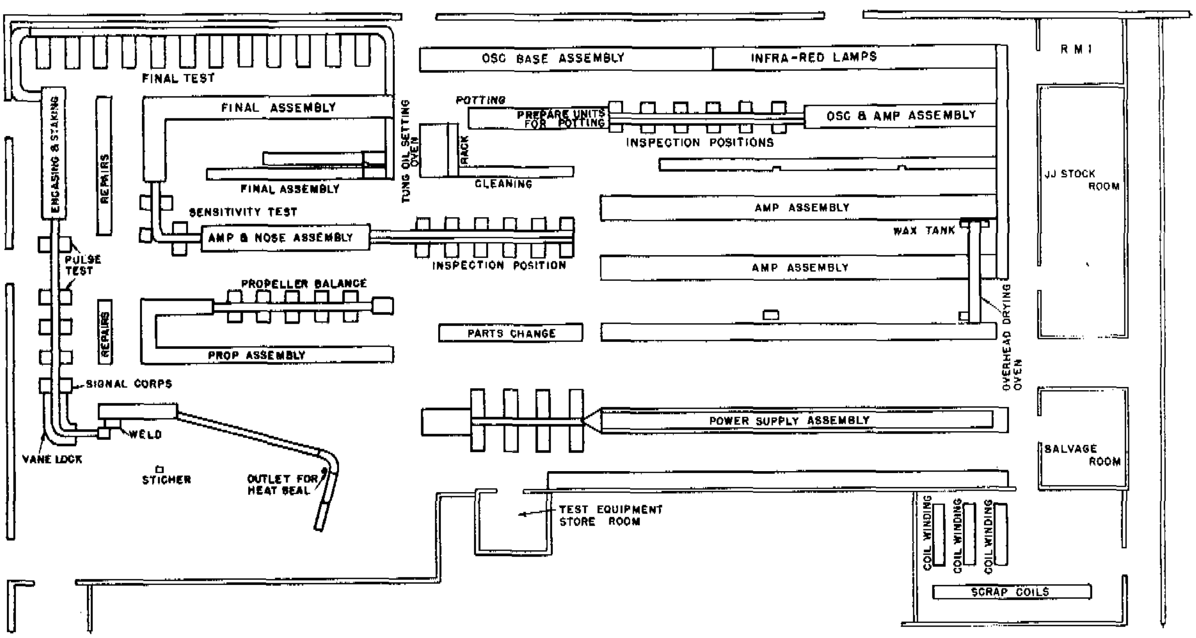


FIGURE 4. Plant layout for assembly lines for the production of T-51 fuzes, Zenith Radio Corporation (reference 17, Figure 4).

6.2.2 Typical Procedures

Usually the production department is handed a layout and a model of the oscillator design.

[redacted]

They are allowed little, if any, latitude in changing the layout of components or the method of oscillator construction. Even the "dress" of every lead is specified, since very slight variations in this respect might cause undesirable variations in carrier frequency from fuze to fuze.

Incoming Inspection

The first and a very important step in the production of satisfactory oscillator assemblies is adequate inspection of incoming components. Those resistors and condensers used in parts of the circuit having any effect on oscillator drive, carrier frequency, or coupling to the radiating system should be 100 per cent inspected. To what extent tubes should be inspected depends on the demonstrated reliability of the inspection at the source of supply. Mechanical inspection should be made of the coil forms for such defects as improper curing (poor mechanical strength), improperly cleaned flash, and uniformity of size. The oscillator mounting plate and tube shield assembly should be checked for flatness, plating finish, full complement of holes (small punches break easily), and quality of soldering of tube shields to the supporting plate. Molded oscillator blocks and all other chassis parts should be inspected for conformance to specifications. Mold pins making small lead holes in plastic parts are subject to frequent breakage and cases have been known where a considerable quantity of pieces have been molded and shipped before such breakage was noticed.

Types of Oscillator Construction

Three different types of oscillator construction were in common use. Many of the mechanical features of the designs have already been discussed and illustrated in Chapters 3 and 4 (cf. Figures 13, 14, and 15, Chapter 3) of this volume. For the purpose of discussion, the types of construction listed below will be covered individually.

Basic types of oscillator construction

1. Phenolic block used for foundation.
2. Thermoplastic block for foundation.
3. Ceramic block used for foundation and incorporating so-called printed circuits.

Each type of construction presented its own peculiar production problems. All of the blocks had one common feature in that they made use of molded cavities to support components and employed cements of various kinds to anchor these components in place.

Figures 5, 6, and 7 show oscillator assemblies employing the three types of construction employed.

Thermosetting Phenolic Blocks

Where a mica-filled phenolic thermosetting material is used for the oscillator foundation, the first step is treatment to insure that all moisture is driven from the block and that the surfaces to which components are to be bonded are made ready to receive the bonding agent. Early production made use of a cement known as Amphenol 912, a product of the American Phenolic Corporation. This material does not adhere well to the glazed surfaces of the phenolic material as it comes from the mold. To overcome this, the blocks are sand-blasted, a treatment which also removes the glaze from the sides of the coil cavities. If these sand-blasted blocks remain very long in a humid atmosphere, there is a possibility of additional moisture absorption. To prevent this, after sand-blasting the blocks are placed in a well-ventilated oven or under infrared lamps and heated to a temperature of approximately 150 F for a period of approximately three hours, after which they are given a coat of the 912 cement, which acts as a sealing agent against further moisture absorption and also furnishes a surface to which later applications of the same cement would adhere more firmly.

It was found desirable by some producers to treat also the larger components, such as tubes and coil forms, with a light coat of the cement and allow same to dry thoroughly before assembly. This was found to aid materially the later cementing of these components in place.

Later in the production program, cements were found that bonded thoroughly with thermoplastic materials without the above sand-blasting treatment.

Thermoplastic Oscillator Blocks

When blocks of thermoplastic material were

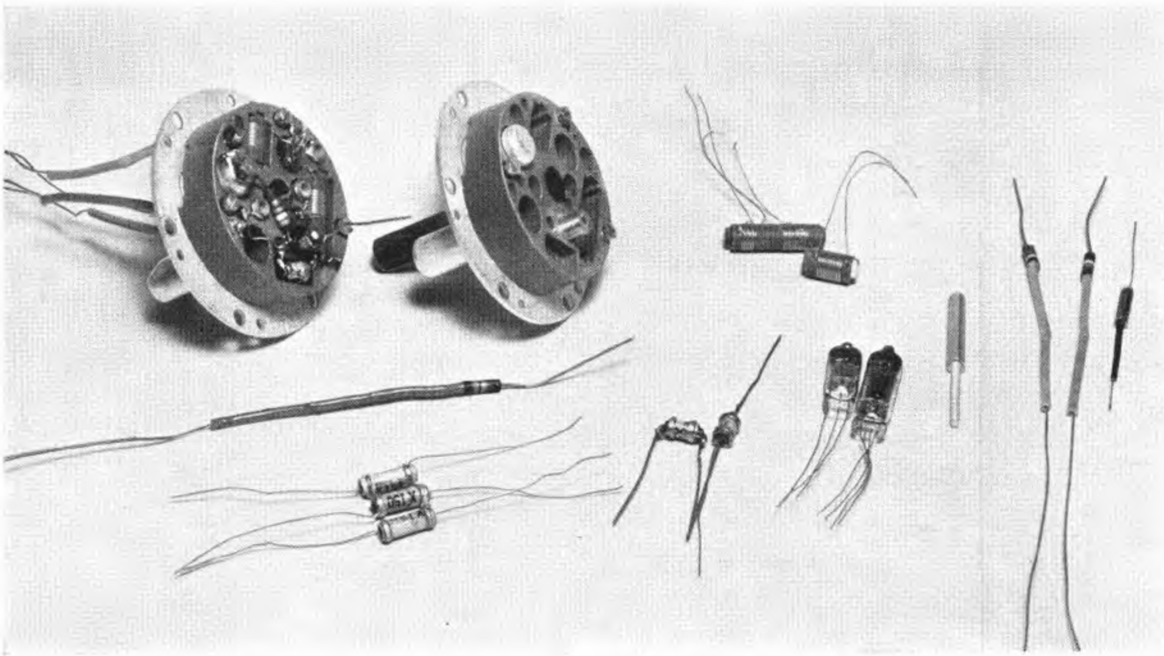


FIGURE 5. Oscillator assembly using thermosetting plastic block.

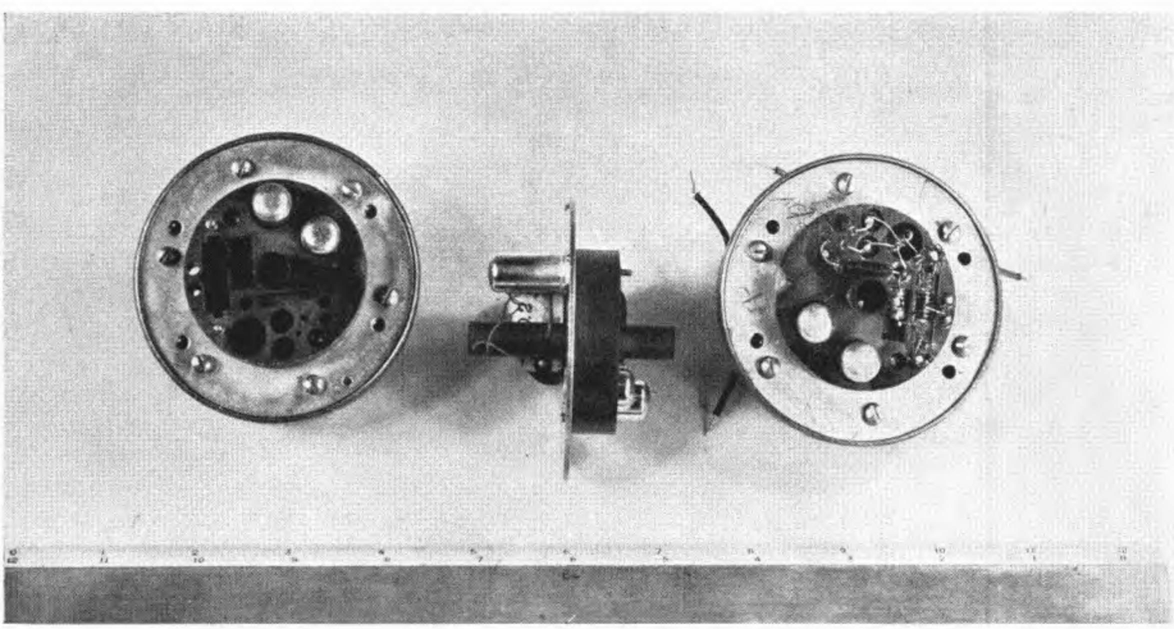


FIGURE 6. Oscillator assembly using thermoplastic block (Zenith photograph).

used, sand-blasting and precoating components with cements was not necessary, since cements were available that fuzed with the plastic material to form a true bond.

The use of thermoplastic material for the blocks had other decided advantages, one of which was the ability to tack down leads along the top surface of the block with a small hot-pointed metal tool which softened the material sufficiently to allow the wires to be embedded firmly into the block at that point.

Ceramic Blocks and "Printed" Circuits

The use of ceramic oscillator blocks with so-called "printed" or "painted" circuits reduced very materially, but did not entirely eliminate, the number of loose components which had to be anchored to the block. The interconnecting wires and resistors were stenciled directly on the ceramic and fired so that they became integral with the block. However, it was still necessary to mount securely such items as coils, tubes, r-f chokes, and condensers. This problem was successfully overcome by the only manufacturer using this type of construction through the use of a thermosetting cement. Ceramic construction forms a special case which is covered in more detail later in this chapter.

Oscillator Coil Construction

In all fuze designs in use up to the end of hostilities, the degree of carrier frequency uniformity that could be obtained was solely dependent upon the uniformity of tube interelectrode capacities, the production of uniform coils, and the reproducibility of wiring layout and stray capacities from unit to unit. There were no lumped capacities used in the frequency-determining circuits. All the above except uniformity of tube characteristics are under the control of the fuze manufacturer. All the factors influence not only the carrier frequency but also the amount of oscillator drive and coupling to the radiating element.

The uniformity of carrier frequencies and oscillator output attained in production is illustrated by Figures 8 and 9, the data for which came from test on groups of approximately 500 units of each of three different man-

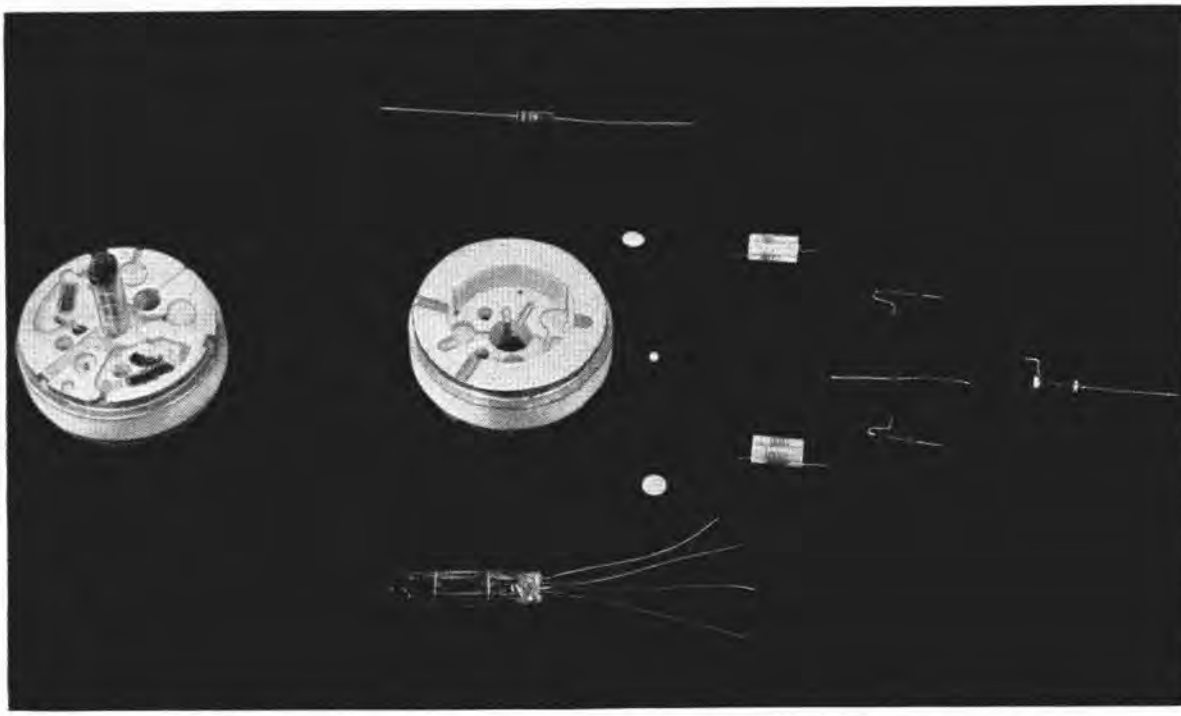


Figure 7. Oscillator assembly using ceramic block (Globe-Union, Inc., photograph).

ufacturers. As a matter of interest, the degree of carrier frequency uniformity achieved in production sometimes proved embarrassingly good, since, as a safety measure, some spread in carrier frequencies is desirable.

The production of uniform coils is, in itself, no mean achievement. In fuzes using a thermosetting mica-filled plastic for the oscillator block, it was customary to use the same material for the coil forms. These forms were usually transfer-molded in multiple molds with register between the two halves of the mold and the necessity for removal of flash.

Coil leads were anchored in the above forms by drawing the wire through accurately drilled holes. These holes were drilled by inserting the form in a drill jig made from a small square block of steel having a close fitting hole for the form and provision for uniquely orienting the bosses on the end of the form with relation to the holes to be drilled. Transverse holes were then drilled through hardened drill bushings at

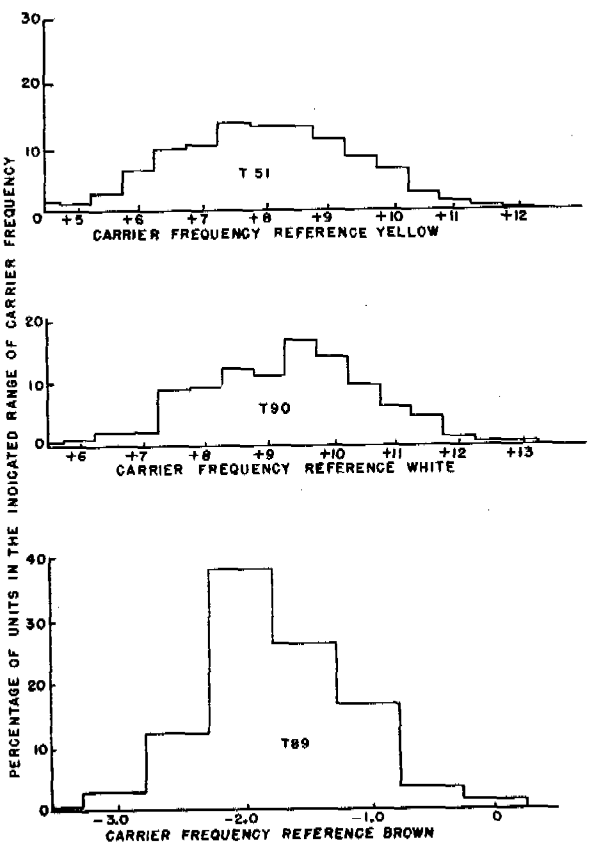


FIGURE 8. Uniformity of carrier frequencies in production of radio proximity fuzes.

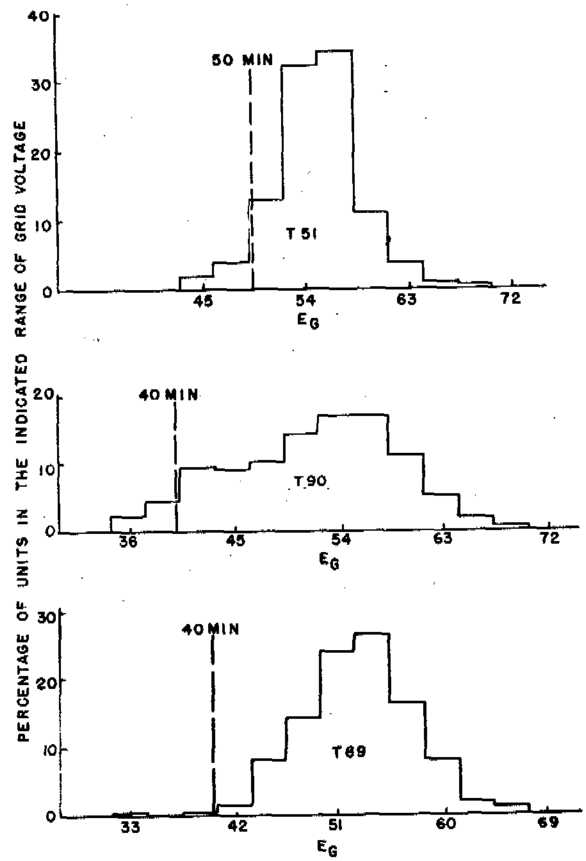


FIGURE 9. Uniformity of oscillator grid voltage in large-scale production of radio proximity fuzes.

removal from the mold accomplished by unscrewing the piece from the cavity which was essentially a tapped hole. A boss on the end of the coil form served as a key for the wrench used for removal. Another method used a two-piece mold with the flash line occurring along two flats on the side of the coil form. This latter method has the disadvantage of requiring exact

the proper places. The mortality rate among the No. 70 drills used for this purpose was very high, due to the highly abrasive character of the phenolic material.

All coils were wound by hand, using simple winding fixtures in which the coil form was turned by a crank which engaged the bosses on the ends of the form. Before winding, the forms

were given a coat of Amphenol 912 cement and dried. After winding, another coat of cement was applied and allowed to dry thoroughly before the coil was inserted in its cavity and cemented in place.

Coil forms molded of thermoplastic material were a decided improvement in that it was possible to anchor the start and ending of the winding by tacking the wire to the form through the use of a small heated metal point. In this manner it was possible to avoid some of the troubles encountered in making uniform coils in which the leads had to pass back through the transverse holes drilled in the form. In some cases, the wire emerged from the form on the bottom or blind side of the coil and had to be dressed back to the top of the chassis block along the outside of the form, giving a long and often indeterminately positioned lead which sometimes resulted in variations in carrier frequency and loading and coupling. With the thermoplastic forms, the actual end of the helix of the coil could be located as desired on the circumference of the coil, and while doubling back of leads was sometimes necessary, at least there was no wire threaded through an oversized hole with the attendant worries as to whether or not the lead could flop around in the field of the coil.

On fuzes using interleaved and center-tapped windings feeding transverse dipole antennas, the center lead was usually formed by twisting together an uncut loop in the continuous winding by means of an auxiliary fixture mounted at right angles to the coil axis and having a crank-actuated retractable button hook arrangement around which was looped this center lead. Turning the crank twists together the loop. This twisted Formvar pair of coated wire then had the insulation removed by dipping it in what was essentially a superheated solder pot. This pot was a metal tube approximately 4 in. long and ½ in. in diameter surrounded by an electric heating element which kept the melted solder at a temperature of approximately 1200 F. Since the pot diameter was small, only a very little area of the solder pool was exposed to oxidation. At the temperature used, the Formvar insulation immediately melted off and wires became well tinned and intimately connected as a single lead. This lead could then be cut to the proper length without unraveling.

The production of coils wound on ceramic forms is covered in a special Section 6.2.3.

Mounting of Tubes in Oscillator Assembly

One of the oscillator components most difficult to mount securely in the assembly is the tube, or tubes if a diode is also used. Many expedients were devised for this purpose; some of the more successful ones are described. As can be seen in Figures 5, 6, and 7 (also Figure 8, Chapter 3), the tubes used for oscillators were, in the majority of cases, oval in shape, having two relatively broad flat sides with narrow rounded ends. The glass seal-off tip on the end of the tube was the only portion that approached the rounded bottom of the tube well, and at best the tube was in contact with the round metal shield at only three points. The problem then is how to overcome this basically weak mechanical design.

By far the majority of early fuze production had the tubes cemented in place. Toward the end of the program, other and better methods had come into use. In cementing in tubes, using the aforementioned Amphenol cement, there was always the possibility of getting too much cement in the tube shield and having it "case-harden." This name is given to a particularly undesirable condition that arises when a hard film forms on the surface of the pool of cement during rapid initial evaporation of the solvent. This hard film then serves as a trap which prevents the further evaporation of the remaining solvent, which in the course of time permeates and softens that portion of the previously dried cement that was presumably holding the tube in place. The same condition also prevailed in cementing coils in the cavities provided for them in the oscillator block.

One method of preventing the above difficulty and of insuring a fairly uniform application of cement all over the block was evolved and promptly dubbed the "fruit jar" technique. Here the cement of carefully controlled viscosity was contained in a round-mouthed jar and the oscillator assembly placed top down across the mouth of the jar. The whole was then inverted so that copious quantities of the

[redacted]

cement permeated every cavity on the block and completely surrounded all components, including the tube. The jar was then returned to the normal position and the surplus cement allowed to drain back into the jar. Sufficient cement was retained around the components in the cavities and tube wells through capillary attraction to form well-defined fillets which, since they contained a minimum volume of cement, dried hard quickly and adequately held the components.

When the above cement dunking process was combined with shaped tube shields, the ultimate obtainable with the cementing method of tube placement resulted. Shields were shaped by inserting a mandrel having approximately the same size and shape of the tube into the normally round tube shield and squeezing the shield around it. The result is a shaped well which is a neat push fit for the tube with several points of contact between the tube and the shield. Even where there is no contact, the separation is so small that cement was retained in the space after the dunking process.

One manufacturer used glass wool wrapped around the tube before insertion in the shield. This wool served to cushion the tube slightly and its compressibility permitted a neat wedge fit of the tube in the shield. Somewhat the same effect was obtained by another manufacturer who used a rubber cushion around the tube.

Toward the end of the production program, a tube potting compound was evolved consisting of 80 per cent microcrystalline wax and 20 per cent polyisobutylene. This molten mixture sets up rapidly upon cooling, providing a secure anchor for the tube. The technique is fast and simple and lends itself admirably to rapid production. It was in use by at least two manufacturers.

6.2.3 Production of Ceramic Oscillator Assemblies

As mentioned previously in this report, the T-132 fuze employed unique methods of construction based on the use of so-called "printed" circuits on steatite plates and blocks. Because of its advantages and potentialities for future use, it seems advisable to present as much information as is available on this type of fuze construction in this special section of this chapter. All the information is from a report by the Globe-Union Company to Division 4, NDRC, on development work performed under an OSRD contract on development work on this type of construction.[8]

This design is built around the process of forming the interconnecting leads and resistors for the circuit by the application of conducting and semiconducting materials directly to the surface of molded ceramic plates or blocks and the subsequent baking or firing of such materials to the extent that they form virtually an integral part of the block itself. The techniques used for metalizing and resistoring are considered by Globe-Union to be trade secrets, although they state in the same report that the general methods are well known to the art. It is important to realize that the end result may be obtained by different manufacturing processes, and it is not essential that the identical processes and techniques employed by Globe-Union be used. The metalizing art is an old development of ceramic and glass industries and there are many widely used methods of metalizing in use by the industry. The resistoring process incorporates the processes developed in the making of variable resistors and this too is a widely known art.

Construction of Ceramic Oscillator Block

The oscillator block is shown in Figure 7. The steatite used has passed the Army and Navy qualifications tests in accordance with JAN Specification I-10 and is known as a grade L-5 ceramic. The properties of the material are tabulated below.

Mechanical	
Specific gravity	2.5
Modulus of rupture	20,500 psi
Tensile strength	9,100 psi
Compressive strength	76,000 psi
Coefficient of thermal expansion	6.9×10^{-6} 20 to 100 C
Moisture absorption	Less than 0.02 per cent
Impact strength	2.0 ft-lb per in.
Electrical	
Power factor	0.110 per cent (1 mc)
Dielectric constant	5.82 (1 mc)
Loss factor	0.640 per cent (1 mc)
Dielectric strength	247 v per mil

Because of the large and intricate shape of the block, it was molded by the wet process to provide better flow characteristics in the mold. Allowance for shrinkage during firing was made. Figure 10 shows the block as it comes from the mold. At this stage, it is completely formed except for the outside dimensions and the two large coil holes. The coil holes were drilled and the outside grooves and proper dimensions were obtained by machining operations. The block is then fired in a kiln to produce a hard, white, vitrified material.

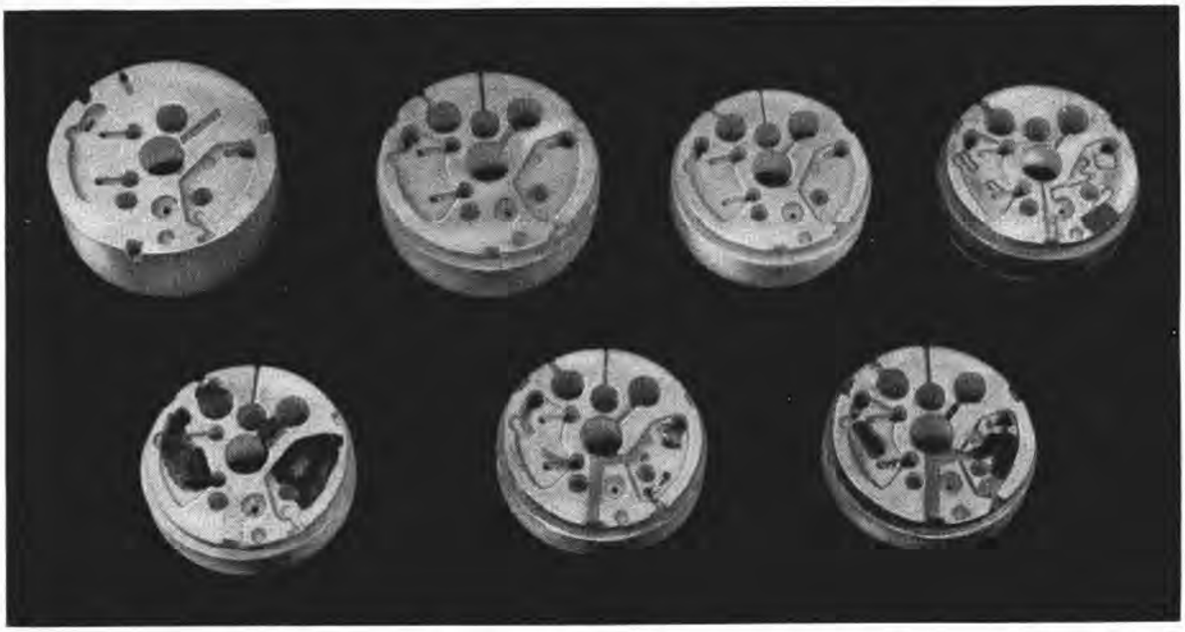


FIGURE 10. Ceramic oscillator block in advanced stages of preparation. View in upper left shows block as it comes from mold. (Globe-Union, Inc., photograph.)

Construction of Ceramic Coil Forms

The oscillator, antenna, and choke coil forms were extruded in the form of rod from the same type of material used for the oscillator block. All three forms were fluted to facilitate winding and both antenna and oscillator coil forms are threaded for accurate spacing of the winding. Threads and lead holes were machine cut in separate operations before the forms were fired.

Metalizing of Oscillator Block

To provide circuit connections and means of fastening other metal parts to the surface of the ceramic, a thin film of silver was applied to the ceramic as described below. Additional coats of copper, tin, and solder were applied to the base coat of silver on certain parts of the block where it was desired to reduce the electric resistance of the coating to a very low value or to facilitate soldering to heavy metal parts, such as the support member and the shell.

The material used for silvering consisted of finely divided silver powder in a suitable vehicle. Before application, the surface of the ceramic was thoroughly cleaned to remove all trace of oil and dirt. After it was applied, the piece was fired in an oven to burn out the vehicle and cause the individual particles to coalesce, forming a continuous film which adheres tenaciously to the surface of the ceramic.

Owing to the irregular shape of the oscillator block, the silvering material was applied by a roll to the edge and by brush to the circuit elements. The edges were silvered to enable the shell and support member to be soldered directly to the block. A tracing template was used to position accurately the location of the surface connections and a small brush was used to apply the material to the surface.

Both edges were given a plating of copper

and tin over the initial silver coat to facilitate soldering. All high-current leads were copper-plated to provide low-resistance paths. The average thickness of the silver coating was approximately 0.0002 in.

Resistoring Process

The process of resistoring on the ceramic surface consisted of applying a suitable resistance material between two metalized elements on the surface. The resistor material consisted of a base of conducting particles, such as carbon black or graphite, in a suitable vehicle. The surface to be coated was covered with a mask having suitable cutouts to outline the areas on which the material was to be deposited and the material was applied to the surface by spraying. After spraying, the resistor was air dried, the mask removed, and the resistor baked to stabilize the resistance. After baking, the resistor was checked for value, and if any adjustment was needed it was made by scraping away a little of the resistance material to increase the resistance value. This was possible, since in the spraying operation the low side of the resistance tolerance was favored. Once the resistor was adjusted, it was given a protective coating of varnish.

A number of factors are important in determining the resistance value. The variable factors are the ratio of the conducting particles to the vehicle or binder, and the length, width, and thickness of the deposit. The air pressure used in the spray gun and the baking time were found to have no appreciable effect on the resistance value.

Resistors made as above described exhibit a slight negative voltage characteristic, as shown in Figure 11, and have good stability under adverse humidity conditions. Tests have indicated that they will dissipate approximately 0.3 to 0.4 watt for a period of 250 hours with a decrease in resistance of only 7 per cent.

Soldering to the Ceramic Surfaces

Special techniques for soldering to the ceramic were used in order that the following requirements could be met: (1) that the soldering process not weaken the ceramic because of heat shock, (2) that initial strains not be developed in the ceramic because of excessive shrinkage of the solder upon cooling, and (3) that the solder not dissolve the thin film of metal on the surface of the ceramic. The use of special low-temperature low-contraction solder such as RM 275, together with preheating of the ceramic, prevents heat shock from occurring. For soldering directly to the silver coating, a special low-temperature silver alloy solder such as RM 297 was used. Use of silver

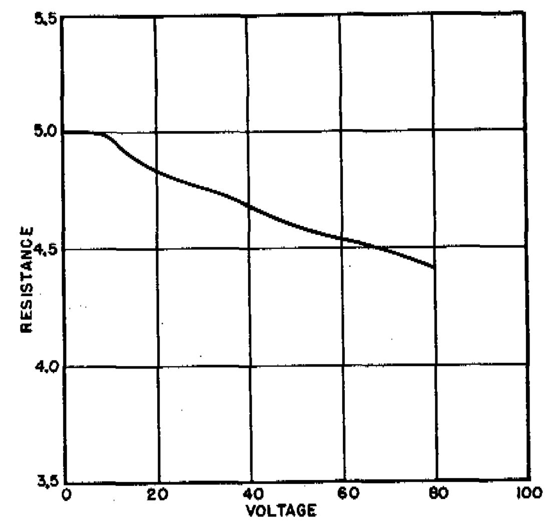


Figure 11. Variation of resistance with voltage for "painted" resistors used in ceramic assemblies.

alloy solder prevents the silver deposit on the surface from being dissolved into the solder, since the solder is already saturated with silver.

Ceramic disk capacitors and wire leads were soldered directly to the ceramic using the appropriate solder. The resulting bond between metal and ceramic was very strong, and it is possible to rupture the ceramic before the joint will fail.

Ceramic disk condensers are soldered directly to appropriately located silvered points on the plates. This was very simply done by heating the disk capacitor to a temperature sufficient to melt the solder, applying a small amount to one face and pressing it against the ceramic plate with sufficient heat to cause the solder to bond to the silvered surface of the plate. Connection to the top side of the condenser is made by soldering a small strip of metal ribbon to

that surface, the ribbon then being connected to any desired point of the circuit.

The soldered joints between the oscillator block and the shell and support member are very critical, since the even distribution of the weight of the unit to the oscillator block is dependent upon the quality of these joints. The block was grooved at these two joints to provide a capillary trough to insure that there was a secure bond between the inner face of the shell and support member to the block. In soldering these joints, the operator was required to use a precut specified amount of solder to insure that the joints were completely filled.

Assembly of the Ceramic Oscillator Block

Assembly of the tubes, coils, and chokes to the oscillator block presented a mechanical problem due to the axial mounting of these parts and the necessity of their remaining in fixed position during setback. Coils, chokes, and tubes were first held in place with polystyrene cement. This cement was chosen because of its excellent high-frequency dielectric properties, but its use necessitated long and careful drying under infrared lamps. The tube was held in place in the oscillator block tube well by wrapping the base of the tube with glass wool and impregnating the wool with polystyrene cement. This made a large mass wetted with the cement and which dried very slowly even under the application of considerable heat. A film would form over the surface, preventing the rapid evaporation of the remaining solvent. In many cases, tubes thus cemented slid out of position during setback, and it was found necessary to devise another method of holding the tube. This was accomplished by cementing the tube in place with a thermosetting cement. The tube was positioned by a jig and the tube well filled with cement up to the level of the leads. In order that the cementing time required for the blocks be reduced to the minimum and the long drying cycle previously necessary for the polystyrene cement be eliminated, the coils and chokes were also cemented in place with the thermosetting cement. A subsequent baking cycle of 3 hours hardened the cement.

All oscillator block assemblies were adjusted to draw a total plate current of a specified value by the addition of a padder resistor of conventional construction mounted axially in the block. After cementing, the necessary value of resistance was determined and the proper resistor attached to the block. Polystyrene cement was used to anchor this resistor in place; however, due to the heavy leads by which it was attached, the resistor was self-supporting and thorough drying of the cement before further assembly work was not found necessary.

The assembled oscillator block, together with all the components entering into the assembly, is shown in Figure 7.

6.3 AMPLIFIERS

6.3.1 Requirements

The essential characteristics of amplifier designs for satisfactory fuze operation have been covered in Section 3.2 of this volume. This previous discussion does not deal with methods of construction nor with the various processes and procedures used in mass production of amplifiers having the desired electric characteristics.

The production department is usually handed a circuit diagram, a model of the type of construction proposed by the engineering department, a set of specifications covering performance of the finished unit, and a list of the precautions and procedures found necessary by the engineering department in their model work on that particular design. From this point on, it is the responsibility of the production department to mass-produce amplifiers having the desired characteristics and meeting the stated specifications with the least possible assistance from the engineering and development group.

The two basic requirements of the amplifier are that it have the desired gain and shaping. At this point it should be pointed out that the term "gain" as used in connection with fuze production does not have quite the same connotation as it ordinarily possesses. The gain of the amplifier system, as such, is seldom meas-

ured in production. What is actually measured is the overall figure of merit known as "millivolts to fire." This takes into account the effective critical voltage of the thyratron and the amplitude of hum (generator ripple) and spurious voltages originating in the amplifier circuit.

The necessity for shaping the amplifier gain characteristic for the desired frequency response has been thoroughly covered in Section 3.2. Examples of the shaping necessary to meet the basic requirements have been shown and methods of obtaining such shaping discussed.

the amplifier which critically affect the gain and shaping should be 100 per cent inspected.

Obviously, the type of circuit employed influences the mechanical layout and construction of the amplifier. The four principal types of construction employed in fuzes that reached the production stage were as follows: (1) sandwich or wafer, (2) ring or collar, (3) printed circuits on ceramic plates, and (4) disk.

Sandwich Construction

A typical amplifier using the sandwich type of construction is shown in Figure 12. In this

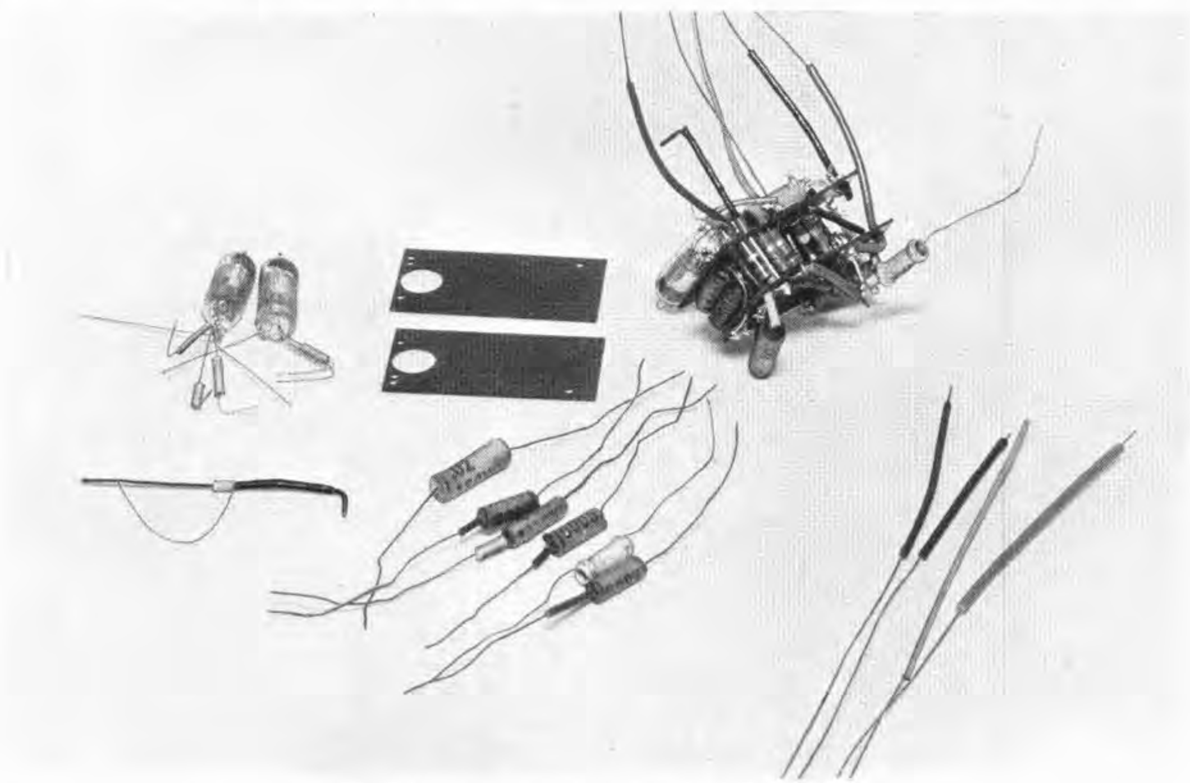


FIGURE 12. Sandwich-type assembly for amplifier.

6.3.2 Procedures

It is the purpose of this section of the chapter to deal with types of amplifier construction and the various manufacturing procedures employed.

As with the oscillator, the construction of satisfactory amplifiers begins with inspection of incoming components. Those components of

construction, two punched linen Bakelite plates approximately $\frac{1}{32}$ in. in thickness are held apart in a suitable jig and most of the resistors threaded through holes in the plates. The two plates are then pushed together with the resistors acting as spacers. This foundation then passes down the production line and has progressively added to it other resistors, condensers, and tubes.

This type of construction has certain advantages and, as usual, certain disadvantages. The construction results in a rigid assembly and shorter leads than is possible with any other method using conventional components. It has one decided disadvantage in that it is not possible to replace a defective resistor after the sandwich is put together. In practice, however, this has not proved as much a drawback as it might seem, since very few amplifiers get through with defective or incorrect resistors in place.

One variation of the sandwich-type construction is shown in Figure 13. This design was evolved because of the need for an unobstructed passage for air to operate an internal turbine (T-82 fuze). Two round Bakelite disks having a central hole for the air tube are utilized. On the two disks are mounted the electric components with some of the larger components sandwiched in between. This type of construction was used by one manufacturer only (Westinghouse), and large-scale production was just beginning at the end of hostilities.

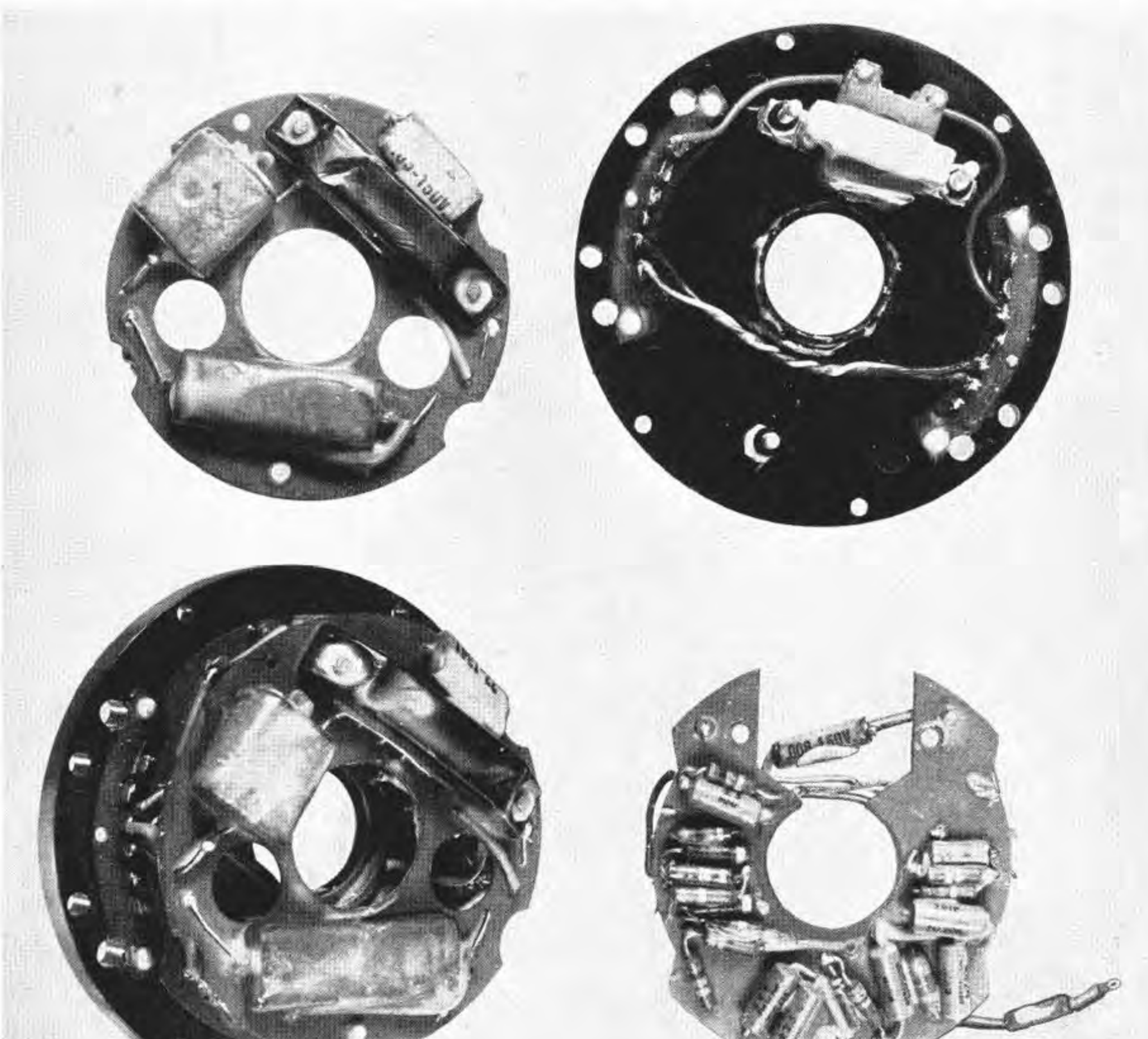


FIGURE 13. Sandwich-type assembly for amplifier with central opening.

Ring Construction

The ring or "dog collar" type of construction found considerable favor with production people. The majority of the fuzes manufactured (particularly T-51) used this type, a typical example of which is shown in Figure 14. In this construction, a strip of Bakelite or fish paper is punched to receive either eyelets or, in some cases, lugs for attachment and interconnection of various resistors and condensers which are attached to one end and, in the case of some manufacturers, both sides of the strip as it progresses down the production line. At some point in the line, the strip is bent into a circle and the two ends riveted together. This ring, or collar, is then inserted in the amplifier cavity. Because of its shape, this design probably makes for maximum utilization of the space available. All components are accessible, and amplifiers having defective components or incorrect values installed can be readily salvaged.

FIGURE 14. Ring-type assembly for amplifier (Zenith photograph).

Ceramic Amplifiers

The "printed" circuit on ceramic plates carries out the same methods of construction as were discussed in some detail in Section 6.2.1. Several different types of amplifiers were designed making use of this process. One, shown in Figure 15, was essentially a sandwich composed of two horizontally mounted ceramic plates containing "printed" resistors and interconnections, between which were mounted the larger paper condensers and tubes. This type of construction was abandoned because of mechanical weakness and replaced by a single ceramic plate mounted on edge for greater resistance to breakage under setback conditions. This amplifier is shown in Figure 16. This illustration shows the ceramic plate amplifier in various stages of production. At the right is the plate after all silvered interconnection jumpers have been fired on. Second from the right shows the plate with all resistors in place, while the two views to the left show opposite sides of the finished amplifier with all paper and ceramic condensers and tubes in place. The methods of applying resistors and interconnection leads on these plates was identical to those described in the portion of this chapter covering oscillators (see Section 6.2.3).

Disk Construction

This disk construction, which is illustrated in

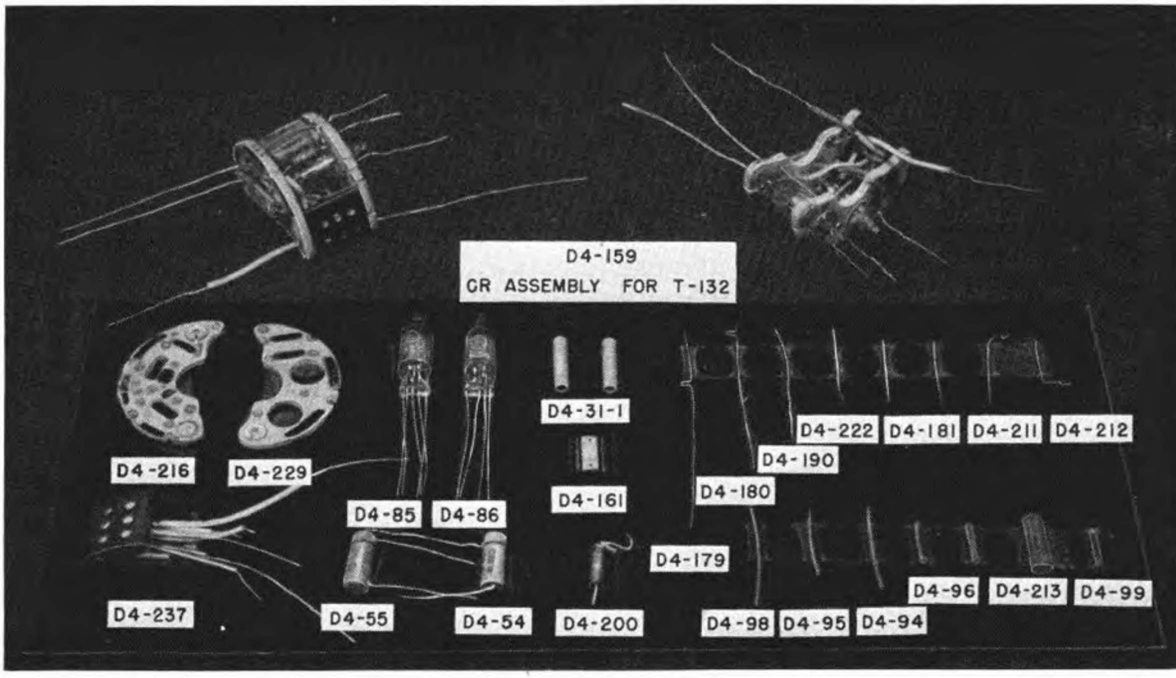


FIGURE 15. Components and assembly of ceramic-type amplifier, early version (Globe-Union, Inc., photograph).

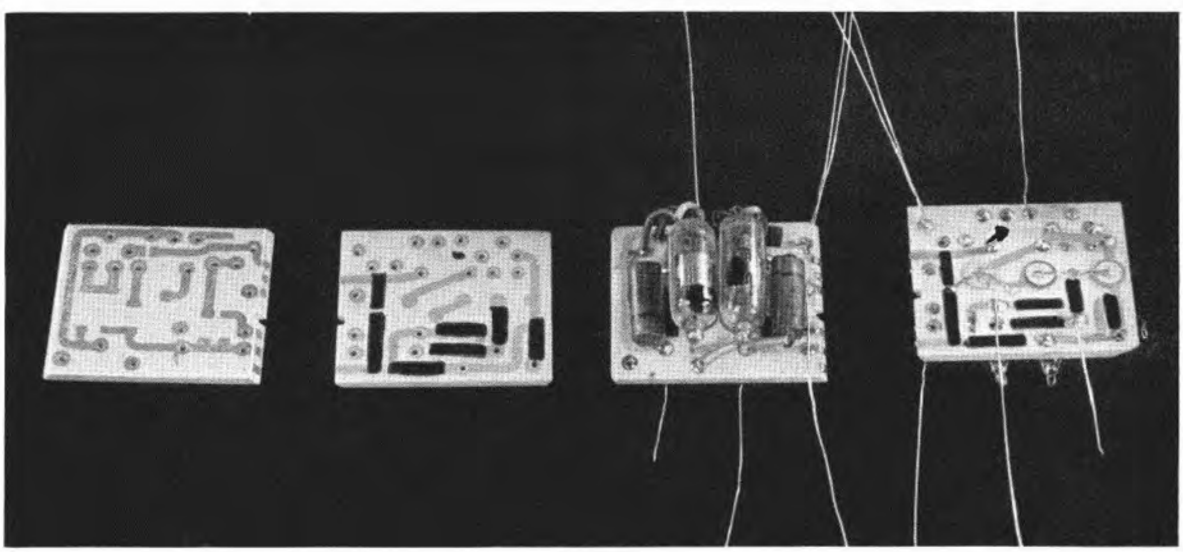


FIGURE 16. Components and assembly of ceramic-type amplifier, late version (Globe-Union, Inc., photograph).

Figure 17, is, in reality, a variation of the sandwich previously discussed. The view shows two types of disk construction as compared with a conventional sandwich assembly shown in the center. The components are laid flat against the upper and lower surfaces of two suitably punched Bakelite strips and wired up, the two plates later being interconnected to form the amplifier assembly. The construction provides for maximum accessibility during fabrication and was particularly favored by one manufacturer.

Gain-Control Condensers

The methods of construction used in gain-control condensers is of considerable interest. These small capacitors, which are used to adjust the gain of the amplifier by control of regeneration, vary in capacitance from approximately 2 to 30 μμf. The majority of manufacturers used a modification of what is termed a gimmick in radio receiver manufacturing parlance. In this device, the capacity is formed between a piece of enameled copper wire, usually about size 18, acting as a mandrel, and a piece of smaller diameter enameled wire wrapped tightly around it. The enamel insulation on the two wires forms the dielectric, and capacity change is made by peeling off more or less of the wrapped wire. This provides a method for changing the capacity in very small increments. One of the finished condensers of this type is shown just below the tubes in Figure 12. In fuzes using the ceramic plate construction, it was the practice to determine the amount of capacity needed by means of a continuously variable condenser, which is part of the amplifier test fixture, and then to select from previously graded groups of condensers the indicated size of fixed capacity, which was then wired permanently into the circuit. This method consumed about the same amount of time as the adjustment of a gimmick wire and has the important advantage that it makes for greater stability in the amplifier and less change of amplifier characteristics with potting. Attention is called to the precautions necessary to protect the gimmick type of condenser from changes in capacity due to the potting materials and process which are described in the next section.

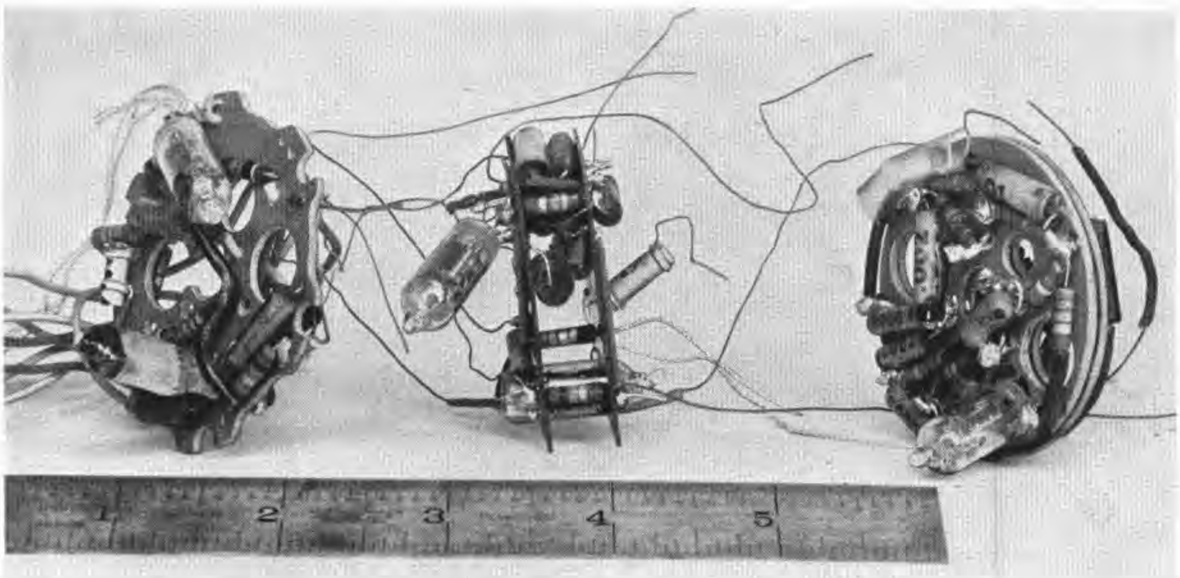


FIGURE 17. Disk-type of amplifier assembly showing comparison with sandwich type. Latter is in center.

Potting and Impregnating Procedures

It was required that all amplifier assemblies be embedded in a potting compound in order that the electric characteristics would remain

[redacted]

stable throughout the various conditions of storage and use. Usually, some preliminary impregnating processes were necessary before final potting (see Section 4.7.6).

In amplifiers using Bakelite or fish-paper strips as the foundation, precautions are necessary to prevent these materials from absorbing atmospheric moisture, which might result in relatively low-impedance paths across critical portions of the circuit and adversely affect the operation of the amplifier.

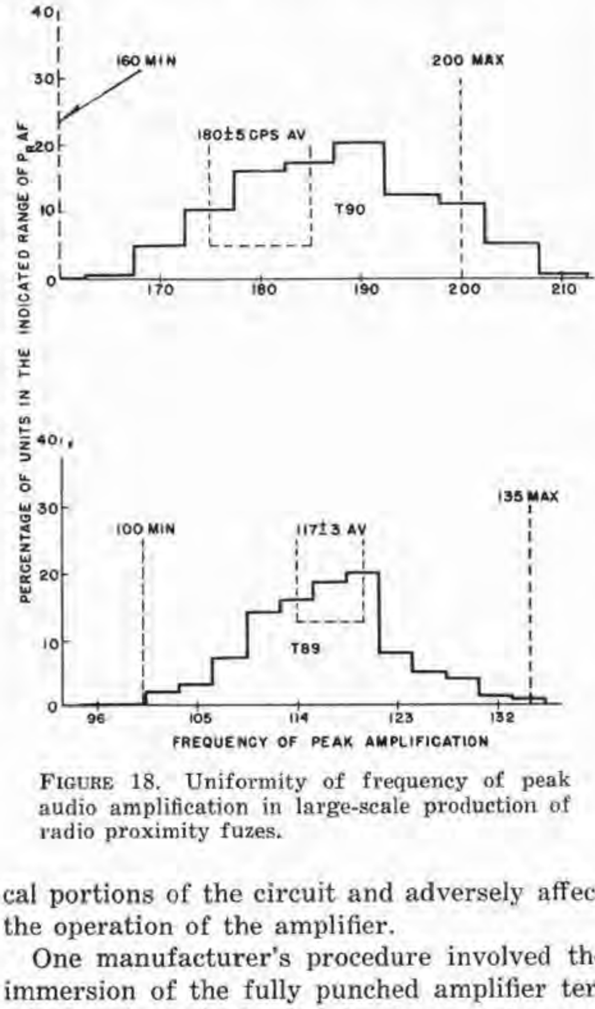


FIGURE 18. Uniformity of frequency of peak audio amplification in large-scale production of radio proximity fuzes.

One manufacturer's procedure involved the immersion of the fully punched amplifier terminal strip and also the insulator strip, used to prevent shorting of components to the metal case, in hot ceresin wax until all bubbling stopped. All the amplifier parts and tubes are then mounted and the entire assembly again impregnated with hot ceresin. After cooling, it is then flash-dipped so that a heavy protective layer of wax is deposited on all parts. These treatments serve to drive out and keep out moisture and at the same time prevent any appreciable, if not all, deleterious effects from the tung oil potting compound.

Essentially the same procedure was followed by other manufacturers, about the only variation being that instead of ceresin, some manufacturers used commercial microcrystalline waxes sold under such trade names as Superla or Halowax.

One interesting variation of the above procedure was used in pilot production of T-30 fuzes. This procedure might prove awkward in large-scale operations because of the larger quantities of assemblies involved. In order to drive out all moisture before impregnation, the day's production of completed amplifier assemblies (before installation of the gain-control condenser) were accumulated and placed on top of cold hard Superla wax contained in pans. These were then placed in an oven, together with an active drying agent, and baked at about 70 C for 8 hours. During the first 4 hours, the wax does not become sufficiently molten to allow the amplifier assemblies to sink below the surface. Thus, the amplifiers were actually baked in a drying atmosphere before impregnation. After the wax completely melts, the amplifiers sink and are cooked for the next 4 hours in the hot wax. Probably the only way to improve on this process is to vacuum impregnate the amplifiers, but this procedure is somewhat awkward where wax is used as the impregnating agent.

The gimmick-type gain-control condensers must be protected against the action of the tung oil potting material. Many schemes were tried, the most successful being the boiling of the finished condenser assemblies, with the ends of the wound wire twisted together, in Zophar Mills No. 1563 Wax at about 150 C for 4 hours to drive out air and fill all cavities with the wax. The condensers are then removed, the free ends of the outside wire clipped short, and the condensers boiled for another 4 hours in order to allow the winding to assume a relaxed or normalized condition. This tends to avoid the effect of further unwinding and the resulting change of capacity after adjustment of the gain of the amplifier.

After the above treatment, the gain-control

condensers were inserted in amplifiers previously impregnated as described and gain adjustment and final check made on the amplifier. The accepted amplifiers were then flash-dipped again in Superla wax at about 75 C to seal off the clipped end of the gimmick wire against moisture absorption.

It is interesting to note the degree of uniformity obtained by various manufacturers in facturer at the Central Testing Laboratory at the National Bureau of Standards.

Before potting amplifiers in the fuze cavities, it is desirable to preheat the fuze by baking in an oven for about 1 hour at 45 C. This baking process accomplishes two results: (1) it dries out the amplifier cavity, and (2) it provides a warm surface for contact with the tung oil. This hastens the polymerization and minimizes

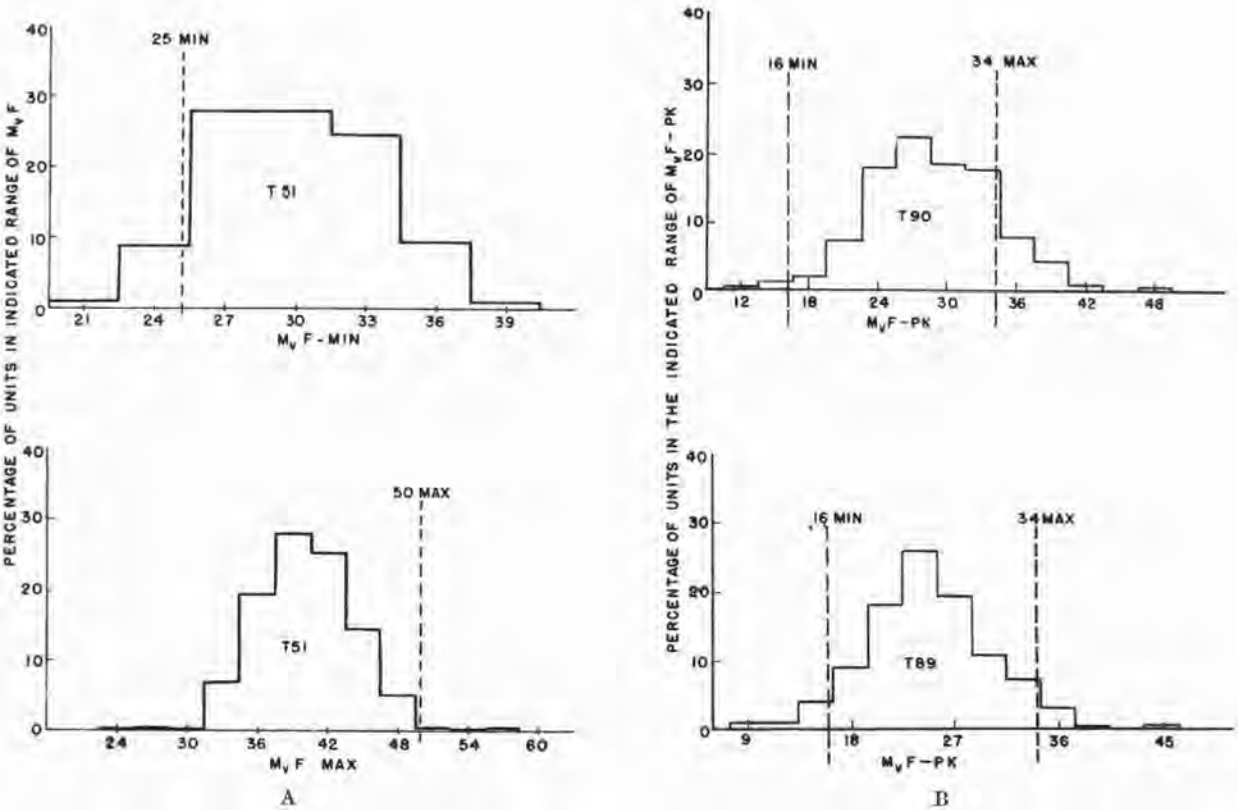


FIGURE 19. Uniformity of millivolts to fire in mass production of three different types of radio proximity fuzes: A, maximum and minimum values of millivolts to fire shown throughout broad pass band of T-51 amplifier: B, spread in peak millivolts to fire is shown for narrow pass-band amplifier of T-90 (top) and T-89 (bottom).

holding the peak audio frequency and millivolts to fire at peak audio frequency to the desired limits. The spread of the peak audio-frequency values around the design center for three different manufacturers are shown in Figure 18. Figure 19 shows the spread of millivolts to fire at peak frequency around the design center for three different manufacturers. These figures are based on an analysis of tests made on approximately 500 units of each manu-

the time during which the active tung oil mix can attack the wax on the amplifier assembly. Wax is a better insulator than tung oil, so that for the purposes of amplifier uniformity, removal of the wax coating must be prevented. If quick polymerization is effected, less harm is done to the wax.

The proportions of tung oil and polymerizer used by different manufacturers varied from 5 parts of tung oil to 1 part polymerizer to as

[redacted]

high as 15 to 1. Since the polymerizer is slightly corrosive, there is some advantage in using as little of it as possible. The high ratio of tung oil to "hardener," however, does make the setting-up time of the material longer.

The polymerizer, or hardener as it was usually called, was available from Westinghouse as an already prepared material, and most quantity manufacturers used this source of supply. Instructions for the preparation of this hardener are included here as a matter of record. The quantities given are for 1 gallon of

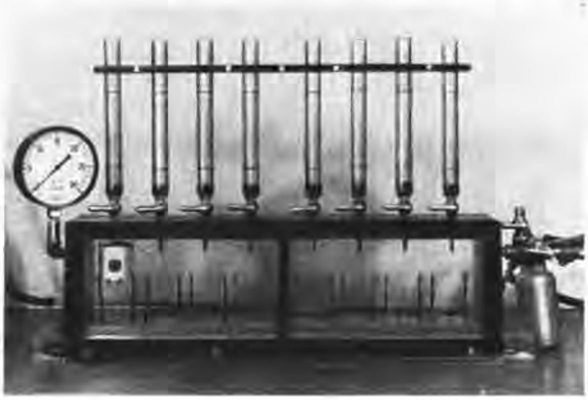


FIGURE 20. Vacuum fixture for potting amplifier units (Globe-Union, Inc., photograph).

hardener: ferric chloride, 6.4 oz by weight; tri-cresyl phosphate, 1 lb 2 oz by weight, castor oil, 3 pt, 7 fluid oz.

Great care must be given to the handling of the hardener ingredients, particularly the anhydrous ferric chloride, in order to guard against contamination with moist air. The anhydrous ferric chloride is added slowly to the tri-cresyl phosphate, stirring constantly with a motor-driven stirrer for 2 hours. This should be done in a narrow-mouthed container to reduce the circulation of air over the exposed surface and the amount of surface exposed. The castor oil is then added and stirred until thoroughly mixed. The hardener is then poured into sealed containers.

The hardener and tung oil are combined and thoroughly mixed by a motor-driven stirrer in a covered container for approximately 5 minutes, after which it is poured into the amplifier cavities. Owing to the viscosity of the mix, several intermediate pourings are usually required as the level gradually settles. After pouring, the fuzes are then returned to an oven held at approximately 45 C and kept there for approximately an hour to hasten polymerization.

Different methods of setting up the potting operation as an integral part of the production line were devised by different manufacturers. In one plant, the conveyor belt was routed by an air-conditioned room in which all mixing and pouring operations were conducted. The units were placed on the conveyor belt and carried through the preheating oven. As they passed a window of the mixing and pouring room, the rack containing a group of units was pulled through the small opening into the potting room where the units were filled. The rack was then placed back on the belt and the units continued on through the oven for a sufficient length of time to permit setting up of the material.

In another plant, the materials were mixed in large refrigerated containers and dispensed from this central point to a number of small containers on the assembly line, also refrigerated, and the units filled by gravity flow from these secondary containers.

Large refrigerated tanks were used on the line of another manufacturer, each holding approximately 15 gallons of the potting mixture. These tanks were equipped with motor-driven agitators to keep the mixture continually stirred to prevent separation or stratification of the hardener and tung oil. Air was applied under pressure to the top of these tanks and the mixture was consequently ejected rapidly into the fuze cavity through flexible plastic tubes.

One manufacturer used a vacuum potting process which is of some interest. The fixture used is shown in Figure 20. The glass tubes were filled with the tung oil mix to the height marked on the tubes. The units were placed in a vacuum tank made of heavy plate glass. After the desired degree of vacuum had been drawn, the stopcocks were opened and the liquid flowed rapidly into the fuze directly underneath the tube. It was claimed by the manufacturer that this method of potting resulted in better penetration of the potting compound into the voids in the fuze cavity.

[redacted]

In addition to the tung oil mixture described above, two manufacturers used what was known as "Glidden" potting compound made by the Glidden Company, of Cleveland, Ohio. This material is a mixture of linseed oil, fatty acids, rosin, magnesium oxide, and alkaline-washed linseed oil. Its use requires the same careful temperature control as tung oil to prevent premature setting up. It is slightly more difficult to pour and is not quite as good mechanically as tung oil, but it has a very decided advantage over tung oil in that it is not as corrosive. One manufacturer using Glidden compound very materially reduced the percentage of amplifiers rejected for change in sensitivity after potting.

FIGURE 21. Arbor press for staking windmill bearing assemblies.

6.4 NOSE ASSEMBLY

Other chapters of this report have covered the evolution of a satisfactory design for the vane bearing and rotating system used on the majority of fuzes. Attention is particularly called to Section 4.3.2.

Production difficulties with the nose assembly centered principally around the problem of obtaining satisfactory bearings for the vane shaft. Early attempts to use porous bronze sleeve bearings proved unsatisfactory because of the high rotational speeds encountered in service. Figure 15 of Chapter 4 shows the type of bearing used on the first fuzes placed in production. Figure 18B of the same chapter shows the bearing in cross section. As can be seen in these figures, the nose bearing somewhat resembled a bicycle wheel bearing. A steel sleeve bearing having recesses at both ends was molded into the plastic nose. Staked to the metal propeller or molded as an insert in the plastic propeller was a shaft having a hardened conical surface at the vane end and a thread on the other end. On this threaded portion was placed a nut having a hardened conical surface similar to the one on the vane shaft. The bearing surfaces of the shaft and nut were selectively hardened by stopping off the unhardened portion by copper plating. This plating inhibited the action of the cyanide case hardening solution. Steel balls were placed in the recessed ends of the bearing sleeve and contacted two sides of the recess and the above-mentioned conical surfaces.

In production, simple fixtures were used to place a predetermined number of balls in each race, and the nut was tightened up by hand until the feel of the bearing was slightly looser than the desired end condition. The assembly was then placed upside down in a staking fixture, shown in Figure 21. This fixture was built from a conventional arbor press and serves to guide a hardened tool having two sharp projections down into the slotted vane lock nut, where these projections shear and force two tabs of metal from the shaft into a smaller transverse slot in the nut, thus keying the shaft securely to the nut and acting as a means for transferring torque and preventing backing off or loosening of the nut. Since there was inevitably some play between the threads on the shaft and the nut, this staking operation also forced the nut farther down on the shaft until all play in the threads was eliminated.

The whole trick of this staking operation was to get the desired degree of tightness or preloading for the bearing without indenting the soft races in the steel insert sleeve. On the side

of the ram (see Figure 21) is an eccentric stop nut which limits the downward motion of the ram and consequently the pressure applied by the spring to the staking tool. On the first try, this stop nut was set at some arbitrary minimum position and the ram advanced until limited by the stop. The nose assembly was then removed from the fixture and the operator judged the feel of the bearings by manually rotating the propeller. Based upon experience, this feel gave an indication of how the stop nut should be adjusted for the next stroke. By this method, a satisfactory bearing was usually obtained in not over three adjustments, with rejects due to overshooting the desired pressure not over 4 per cent. A reasonably intelligent operator could be trained for this operation in a day.

Associated with the above bearing design was a coupling shaft whose limitations have been outlined in Chapter 4. The design of the rotating system was probably the best possible in view of the necessity of using something other than commercial ball-bearings, which were not available in the quantities needed for the program at the time fuze production was started. When commercial bearings became available, it was possible to change to a design which is illustrated in Figure 16, Chapter 4. In this design, the shaft extending back to the generator was integral with the vane. There was enough play in the commercial bearing to allow for small angular misalignment between the generator shaft and the nose. The bearing was dropped into place in the recess provided in the metal insert molded in the plastic nose and held in place by either staking or rolling over the edge of the recess. There was no fitting of bearings or variation in the tightness of the bearings caused by human judgment.

It was necessary, in order to reduce vibration, to balance the vane dynamically. The equipment for doing this is described in detail in Section 4.6. All quantity manufacturers used equipment basically the same as the laboratory setup described in that chapter. Some of them experimented with different types of transducers in order to get away from the limitations of the displacement-type crystal pickups used in the first design, which proved unsatisfactory in service. Aside from erratic behavior, the pickup acted as a microphone and the output arising from its operation as such sometimes interfered with the voltage generated in the pickup by the vibration under investigation. At least one manufacturer used a dynamic pickup in conjunction with a simple RC network to convert the output, normally proportional to velocity, to a value proportional to displacement. This same manufacturer also experimented with a very rigid (high resonant frequency) nose mount in the balancing fixture instead of the low-period flexible mount described in Chapter 7.

After the approximate amount of the unbalance had been determined, together with the angular relationship of the heavy point to a fixed mark on the vane, weight was removed by either clipping the edges of the metal vane with a pair of tin snips or drilling small holes in the appropriate place on the plastic vane. Because of the greater number of discrete points at a maximum radius from which weight could be removed on the metal vane, these were very much easier to balance in production than the plastic ones.

6.5 POWER SUPPLY AND ARMING

For the purpose of discussion, the power supply and arming systems used on radio-type proximity fuzes can be divided into two general classifications. In one type of fuze, the power supply and arming system was combined in a separate subassembly adaptable to being farmed out to subcontractors and later assembled to the fuze head at the plant of the principal manufacturer. An example of a power supply of this character is shown in Figure 22. In the other general classification, the components making up the power supply are distributed throughout the fuze assembly in such a manner as to preclude the identity of the power supply as a separate assembly. Examples of this type of construction are shown in Figures 23 and 24. In Figure 23 the generator proper and its turbine drive was installed below the fuze head, while the rectifier and filter condensers associated with it were distributed in various portions of

the upper cavity containing the other electronic components. In Figure 24, the generator, with its driving turbine, is contained in the nose and

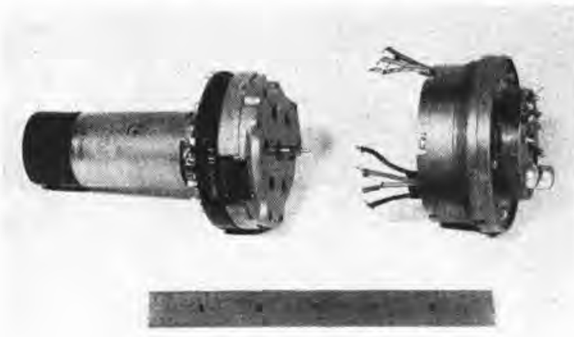


FIGURE 22. Integral power supply (left) as received from outside manufacturer for assembly into radio proximity fuzes. Oscillator-amplifier assembly is shown at right.

the rectifier and filter components in the main body of the fuze.

6.5.1 Requirements

The performance desired of a power supply can be easily specified in terms familiar to the electrical industry. No unfamiliar concepts are involved. The supply must deliver plate, filament, and bias voltages which fall within speci-

FIGURE 23. Power supply and arming system for T-82 fuzes.

fied limits over the expected range of speed variation. The degree of filtering can be specified in terms of permissible modulation of the plate supply.

Likewise, the mechanical specifications are easily understood. The bearings must be capable of standing high-speed operation and the arming system must perform its function within a given number of revolutions of the generator shaft.

Since the fuze has such a short operating life, it is permissible to overload some of the electric components. This is a particularly fortunate circumstance because the limited space available does not permit the use of components having the safety factors usually specified.

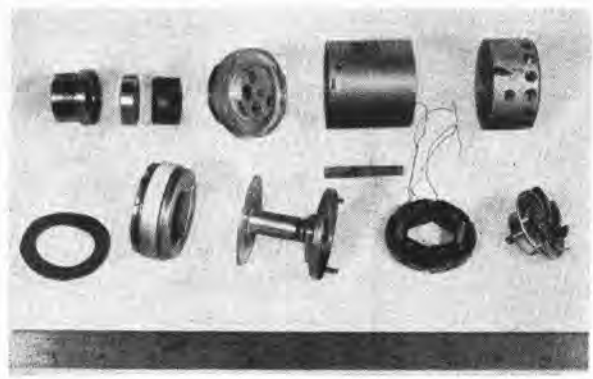


FIGURE 24. Mechanical parts and power supply for T-132.

6.5.2 Procedures

GENERATOR CONSTRUCTION

The housing used in early models of generators were of molded Bakelite. This material proved to be unsatisfactory because of difficulties in maintaining the desired dimensional tolerances and was abandoned after unfavorable pilot production experience in favor of either die cast or stamped and drawn frames. A power supply using die cast housings is shown in Figure 25 and one using a drawn case is illustrated in Figure 26. The die cast generator housing required a relatively large amount on machine work on the rough casting in order to make it usable. The tooling designed for this purpose was somewhat elaborate and ingenious. In one manufacturer's plant, four multiple spindle drilling heads were used, each one equipped with a five-position indexing platform with provisions for rapid positioning and locking of housings in position. The four heads per-

formed 60 operations on each housing and produced one completely machined generator frame every 90 sec. On each piece there were 18 drilling, 27 counter-boring, 3 counter-sinking, and 12 tapping operations.

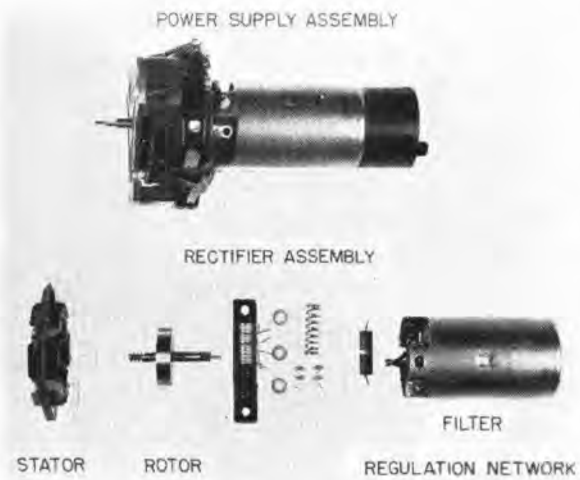


FIGURE 25. Power supply using die cast generator.

The drawn shell housing was probably the most feasible from a production standpoint, and the majority of power supplies built used this type of construction. This type of generator is shown, in considerable detail, in Figure

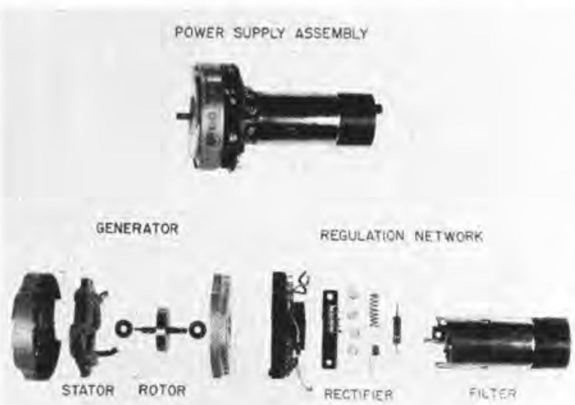


FIGURE 26. Power supply using stamped and drawn shell for generator.

27. The shell consists of two mating drawn pieces which contain within themselves all load holes and stator spacing and locating surfaces. The only machined piece used in the shell was the bearing cups, which are clearly shown in the illustration.

Both sleeve and ball bearings were used in the production model generator. The sleeve bearings were of sintered porous bronze. In order to make sure that an adequate supply of lubrication was available, even after long storage periods, some manufacturers used saturated wicks in connection with these sleeve bearings. Later, ball bearings were used when the supply of such bearings became adequate to support the heavy requirements of the fuze production program. These bearings make possible a "tighter" generator assembly, end play and side play being reduced to a minimum. In order to keep production up and costs down, most manufacturers used sleeve-bearing fits some-

FIGURE 27. Details of generator using drawn shell construction.

what looser than was generally considered desirable. The use of ball bearings also provided a larger margin of safety against bearing failure during production testing. Where ball bearings were used, cup-shaped beryllium-copper spring washers were used to take up end play and provide for slight dimensional differences. Since the amount of take-up varied within wide limits from fuze to fuze, additional shimming was provided by a series of punched Bakelite washers approximately 0.010 in. thick.

Generator coil construction took two general forms, one using six bobbins, illustrated in Figure 24, and the other a single serpentine coil assembly containing both plate and filament windings such as illustrated in Figures 26 and 27. Two serpentine windings were used on some types of generators, the second winding passing over the opposite side of the stator pole. The cost of the bobbin-type winding was

[redacted]

greater than the single serpentine coil. In addition, the bobbin-type construction had several other disadvantages. It was necessary to provide six molded bobbins, wind each bobbin with two separate windings, and interconnect the six in the proper manner. Compared to this, construction of the serpentine winding was relatively easy and inexpensive. The plate and filament windings were wound one on top of the other in a simple collapsible wooden form. After removal from the form, the coils were taped on the same type of equipment used for taping small motor windings. The taped winding was then shaped in a simple fixture having interleaved castellated projections which pressed the taped coil into the characteristic serpentine shape. The coil was then slightly distorted and inserted in the stator and expanded into position. The entire stator stack was then vacuum impregnated.

The impregnation of both bobbin and serpentine-type stators was essentially the same. The stator assemblies were placed on a rack and dried in an oven at 250 F for approximately one-half hour. While still hot, the rack was immersed in a container of suitable varnish (Irvington Varnish and Insulation Company No. 9 Clear Drying Varnish). For proper penetration, it was necessary to hold this varnish at a specific gravity of 0.855, naphtha or benzene being used as a thinner. The container with the immersed coils was then placed in a vessel and evacuated to at least 25-in. mercury vacuum for 15 min. The vacuum was then released and the stator assemblies removed from the varnish, placed in a centrifuge, and the excess varnish extracted. The stators were then allowed to air-dry at room temperature. Both bobbin and serpentine coils were random wound.

Generator shafts were made of stainless-steel ground precision finished stock, with the worm cut on a standard thread grinder. This worm was cut in one pass with a floor-to-floor time of approximately 3 sec. After cutting the worm, it was found necessary to de-burr the machined portion. No method of generating the worm was devised to get around this time-consuming hand operation. The shafts were held in the rotor insert by a knurled portion of the shaft. This knurling increased the diameter approximately 0.002 in. and provided a push fit of the shaft into the hole in the rotor insert.

The Alnico rotors used were made either by casting or sintering the Alnico material. By far the larger number of generators produced employed cast Alnico IV rotors. In early models of the generators, the soft steel or brass insert engaging the shaft was held in place in the central hole of the rotor by cerromatrix alloy. This procedure proved unsatisfactory for two reasons. First, the alloy has a very low melting point and sometimes loosened from the heat generated in the bearings by long test runs. The mechanical problem of centering the hole in the insert with respect to the outside diameter of the rotor was solved after some trouble by holding the outside diameter of the rotor and the inside diameter of the bushing in a concentric collet-type fixture while the cerromatrix was poured in the space between the rotor and hub. This method of holding hub was abandoned later in favor of a solid soft steel insert cast in the center of the Alnico rotor. The cast blanks were next ground so as to have the two sides parallel and to the proper dimensions. These blanks were then centerless ground to the proper outside diameter, after which they were placed in a collet-type chuck and the shaft hole drilled and reamed to the proper size.

Some trouble was experienced in the beginning of production with inability of the rotors to stand high rotational speed. The manufacturers of the rotors solved this problem so successfully that rotor breakage from this cause was practically unknown toward the end of the production program.

It was at first thought that rotors could be held so close to the proper dimensions by the sintering method of manufacture that some of the grinding and sizing operations could be eliminated. This, however, proved not to be the case.

The rotors were magnetized in several different ways. Practically all manufacturers used a fixture having six retractable pole pieces around each of which was wound the magnetizing coil connected in such a manner as to provide opposite magnetic polarity to adjacent poles. Some manufacturers advanced and with-

drew the pole pieces with all cams actuated simultaneously by one handle. Other manufacturers used a fixture in which each pole was attached to the piston of a small air cylinder with the pole pieces advancing with air pressure and withdrawing through the action of a spring built into the cylinder assembly. Figure 28 shows a fixture of this type. Some manufacturers magnetized rotors using a bank of storage batteries as a high-amperage low-voltage source. Considerable difficulty was had with the electric contacts because of the large currents they were required to pass. A more satisfactory method of doing the job was worked out by some manufacturers who charged a bank of condensers to approximately 300 to 400 v using a small receiver-type power supply to furnish the charging current. These condensers, having a total capacity of several hundred microfarads, were then discharged instantaneously through the magnetizing coils. A grid-controlled gaseous discharge tube was used to trigger the discharge and by its unilateral conduction prevent oscillation. Another manufacturer used a fixture employing somewhat the same idea as the one just discussed but discharging the condensers through the primary of a step-down transformer having a secondary of a very few turns which was coupled to single-turn magnetizing coils made of heavy copper strap. All these devices served to saturate the magnet material in a satisfactory manner.

Arming System

The mechanical construction of the arming system employed in various production fuzes have been adequately covered in Chapter 4. Since no particularly new procedures were involved in the construction of these components, no discussion of them is considered necessary in this chapter.

Electric Components

The electric components in a power supply consist of filter and regulating condensers, resistors and the selenium rectifier assembly. The resistors used were standard commercial items, and as mentioned previously all were operated under conditions where the rated dissipation was exceeded. The resistor in the regulating network normally rated at ½ watt was called on to handle in some instances as much as 3 watts for the short operating time of the fuze.

The filter condensers used in a majority of the fuzes were specially designed and some difficulty was experienced at the beginning of the production program in obtaining a satisfactory product. The condensers were built around a hollow tube through which the slow-speed shaft

FIGURE 28. Typical fixture for magnetizing rotors in generator power supplies (Globe-Union, Inc., photograph).

passed. Two types of construction were employed. One type employed a simple construction in which condenser sections manufactured in the conventional manner were dropped in place between two concentric cardboard tubes. These sections were then interconnected and the whole assembly potted. Since there were voids between the condenser sections, this was not the most effective way to utilize the space available. Nevertheless, the first manufacturers contacted felt that this design was more feasible from a production standpoint than the second type to be described. In this second type of construction, later used by all manufacturers, the two filter sections and the regulating condenser were all wound in one operation, the leads being brought out by means of tabs laid between turns. While the working voltage of the condensers was only 150 volts, the test voltage was 300 volts. This necessitated a two-paper construction. Manufacturers, however, were able to build into the space available sufficient capacity for the purpose.

In fuzes where the filter and regulating condensers were in the main body of the fuze instead of a separate power supply, small sections of conventional construction were employed. One fuze used a hermetically sealed oil-filled unit.

In the early developmental stages, it was proposed to use copper oxide rectifiers primarily because small buttons of a suitable size were already available and no new techniques had to be devised to produce a size suitable for the fuze. Because of the unsatisfactory temperature characteristics of copper oxide rectifiers, these were soon discarded in favor of selenium rectifiers. When first approached on the proposition of producing a rectifier suitable for fuze applications, the manufacturer, who at that time was the largest producer of such devices, expressed considerable doubt as to whether a selenium rectifier button could be produced in the size required. Selenium rectifier elements had never before been produced in anywhere near the quantity under discussion.

At the time, all selenium rectifiers were made with a central hole through the disk for a mounting stud which held the stack in compression. Engineers at the Bureau of Standards proposed a wholly novel type of construction which was immediately adopted and placed in quantity production. As can be seen from Figure 29, there is no center hole in the disk. The active area of the disk is the center depressed area. Contact to this active area is by means of a low melting point metal coating sprayed so that it extends up the side of the depression and overlaps the top to a distance of approximately $\frac{1}{16}$ of an inch. This overlapping area contacts the base metal of the next disk. The whole assembly is contained in a suitable holder under compression from a small spring which applies approximately 6-lb pressure.

The manufacturer first approached as a supplier for these rectifier disks deserves considerable credit for the development of the manufacturing process and the clever tooling worked out. The method of manufacture and tooling was adopted with some modifications by the other manufacturers engaged in the production program.

In the production of the rectifier disks a sheet of a base metal was first sand-blasted or chemically treated to provide a surface to which the selenium would adhere. These sheets, each one large enough for approximately 100 rectifier buttons, were then punched out in such a manner that the portion which eventually became the button was projected halfway through the metal. At the same time, register holes were punched for aligning the plate in the fixtures subsequently used. The plate was then covered with a mask which left visible only the upraised round portions and selenium powder applied to the exposed surfaces. The plate was then placed in an oven and heat-treated to change the powdered selenium to a suitable form. Various manufacturers used different procedures for this step in the manufacture of rectifiers. In most cases it was considered a trade secret which they preferred not to discuss. After the above treatment, the plates were placed in another fixture and a covering of paper cemented to the tops of the buttons. In the paper there was a hole which registered exactly in the center of each button. Over this another mask was placed which contained a slightly larger hole. A low melting point alloy similar to Wood's metal was then sprayed over the top of the masks. This metal formed the conducting medium contacting the center of the selenium button and extending up the sides of the recess and overlapping the edges.

After spraying, the mask was removed and the plate transferred to a fixture containing a multiplicity of small plungers, each one contacting the small area of counterelectrode material for a disk. In series with each plunger was a resistor serving to limit the current flowing to the button during the electroforming process. As the resistance of the button was built up during the formation of the barrier layer, the voltage drop across the button became higher and higher until the desired reverse current resistance was attained. After electroforming, the plate was placed in an accurately registered die and all the buttons punched out of the plate in the finished form shown in Figure 29.

Another supplier of rectifiers used a method of manufacture which resulted in a superior end product, particularly with respect to uni-

[redacted]

formity. Deposition of the selenium on the base metal was accomplished by evaporation in a high vacuum and subsequent curing at the proper temperature to obtain the desired crystalline form. Plates of base metal large enough for about 100 rectifier disks were processed in the evaporation chamber. They were then covered with a mask of high-quality paper perforated with small holes to outline the actual areas, the paper being held in place with a coating of thermosetting plastic. A counterelectrode material similar to that previously mentioned was sprayed over the entire area of the disks by using a skeleton of a previous punching operation as a mask. By extending the counterelectrode material over the whole surface of the paper, the contacts between adjacent disks in the finished rectifiers were maintained continuously during severe shock and vibration. The problem of microphonics in rectifiers was resolved by this expedient.

The buttons were assembled into completed rectifiers and tested as a complete assembly. In the early days, considerable trouble was had with defective buttons made by the first process described. Figures 30 and 31 show some typical defects. The illustrations are self-explanatory.

Contact to the buttons was effected by means of small metal tabs or flags interleaved between buttons and projecting through the sides of the case. One manufacturer used small coiled wire forms for this purpose in place of flags.

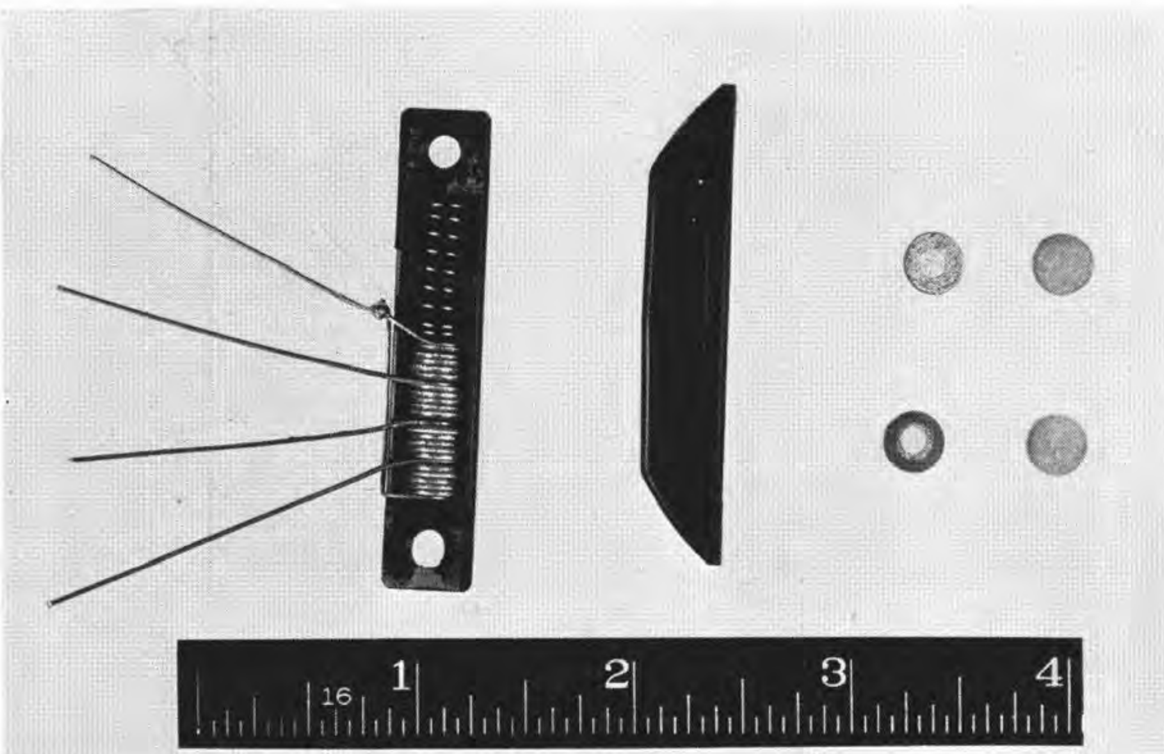


FIGURE 29. Rectifier assembly using selenium disks.

6.6 MISCELLANEOUS PRODUCTION TECHNIQUES

As was to be expected, each manufacturer used techniques which had proved most desirable in his experience in the manufacture of other electronic equipment (radio receivers in most cases). Some manufacturers presented the smaller assemblies to a fixed soldering iron while others kept the units in a holding fixture and applied the soldering iron to the work. Each method has its own advantages and dis-

[redacted]

advantages and just which is best depends on the nature of the operation.

Considerable difficulty was had in obtaining solder having high tin content due to the scarcity of this metal. As a result, some manufacturers were forced to use low tin alloys which made the soldering operation somewhat more difficult. Actually, a solder having 63 per cent tin and 37 per cent lead has the lowest melting point of any lead-tin alloy, 183 C. The plastic range, i.e., the range of temperature in which the solder is in molten form, is also shortest with this alloy as is to be expected. The following tabulation shows the melting point and plastic range of various solder alloys.

Tin-Lead	Melting point (degrees centigrade)	Plastic range (degrees centigrade)
40–60	265	82
45–55	252	60
50–50	239	55
55–45	223	39
60–40	202	19
63–37	183	<5
70–30	195	11

In normal times, most manufacturers prefer to use a solder having at least 50 per cent tin and some insist on a 60 per cent tin alloy. The necessity of using alloys of 35 and 40 per cent tin introduces problems in obtaining properly soldered joints.

Most solder specifications are written to allow a ±5 per cent variation in the percentage of tin used. Since tin was not only expensive but scarce during World War II, most of the 40-60 solders used actually had less than 40 per cent tin content. This necessitated the use of more heat on soldered joints, with the added bad effects on resistors and condensers. There was also considerable danger that the leads might be displaced while the solder was taking such a long time to reach a solid state. The use of high tin content solders is particularly desirable when soldering to metal parts embedded in thermoplastic materials.

Another particularly troublesome point was the poorly tinned lead wires on the resistors of some manufacturers. Resistors were often received with a waxy gum on the leads that made soldering to them particularly difficult. No really satisfactory method of cleaning this material from the resistors was evolved.

It is interesting to note the various methods used by different manufacturers in handling fuzes along a production line, particularly after the oscillator and amplifier assemblies had been combined. Some manufacturers placed the fuze

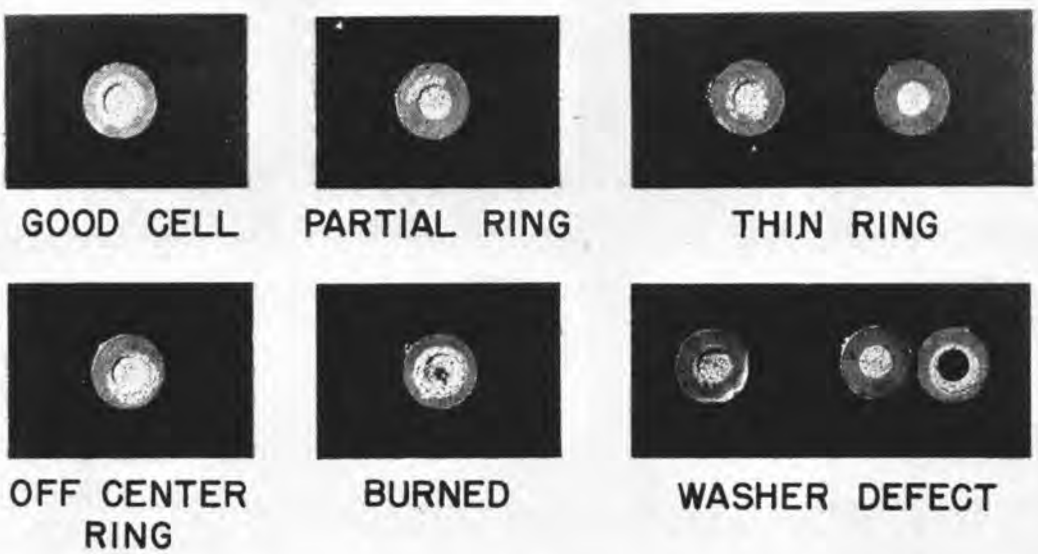


FIGURE 30. Typical defects in selenium rectifier disks.

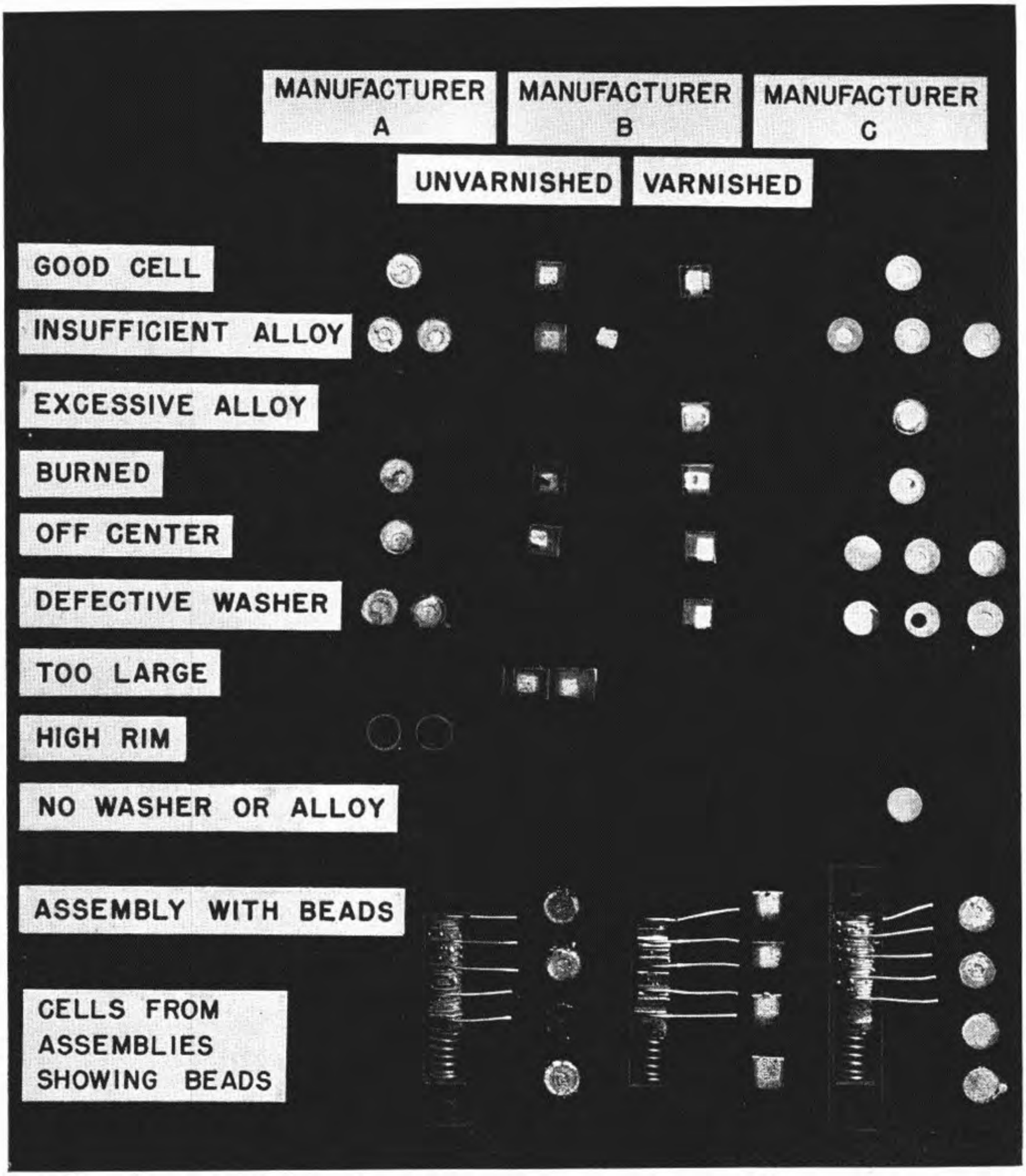


FIGURE 31. Typical defects in selenium rectifier disks from three different manufacturers.

in a simple wooden fixture which was passed on by hand to the next operator. Others used a trough in which the whole fixture was a sliding fit. The operator would remove the fixture from the trough, perform the necessary operation, replace the fixture in the trough, and shove it on to the next operator. A portion of

FIGURE 32. Assembly line for oscillator units. Oscillators are moved along trough shown on left side of photograph (Emerson photograph).

an oscillator assembly line is shown in Figure 32 with the trough used to pass on assemblies shown at the left. Another used a conveyor belt slowly moving along in front of each position. To this conveyor belt was fastened a fixture holding the unit. The operators were required to perform the operation while the units were on the move, so to speak. Overhead conveyors were also used. Figure 33 shows such a system feeding finished units to a final test area in the plant of one manufacturer. Figure 34 gives a close-up of a final test position showing the small pockets attached to the belt in which the fuzes were held.

6.7 PRODUCTION TESTING

The design of test equipment for proximity fuzes is covered in Chapter 7 of this report. Test equipment development for the fuze program was the responsibility of the Central Laboratory of Division 4 at the National Bureau of Standards [NBS]. Since the specifications for the fuze were written around tests performed on equipment of NBS design, most manufacturers followed the NBS designs in the construction of production test equipment.

More testing was done in pilot production than was deemed necessary or desirable in quantity production. Not only were more tests conducted, but it was necessary to record in considerable detail data on the performance of every unit in order that the known characteristics of fuzes might be correlated with subsequent performance of the unit in field tests. However, when meters have to be read to an exact value and perhaps recorded, the process takes more time than would be feasible in mass production. For production purposes, practically all indicating instruments can be marked with go and no-go limits and fuzes tested in a very short time.

In most cases manufacturers followed a test schedule similar to the following. Oscillator assemblies after completion were tested for (1) carrier frequency, (2) diode voltage (in the case of oscillator-diode [OD] units), and (3) grid voltage (in the case of reaction grid

FIGURE 33. Assembly line for radio proximity fuzes showing overhead conveyor for moving completed fuzes to final test position (Emerson photograph).

detector [RGD] units). Amplifier assemblies were given a preliminary test after construction, principally to see if the circuit was functioning. After interconnecting the oscillator and amplifier assemblies and before potting, a rather complete check was made on the combined "head," the following information being

noted on each unit: (1) millivolts (input to amplifier) to fire (the thyratron) at the peak audio frequency, (2) millivolts to fire at two frequencies spaced from the design center frequency in such a way as to serve as an indication of the shaping of the amplifier, (3) peak audio frequency, (4) oscillator frequency, and (5) diode or grid voltage.

After potting, most manufacturers tested the fuze head to determine whether or not any significant changes had taken place because of potting. In some cases, this test was abandoned after experience had shown that the number of units rejected at this test position was negligible.

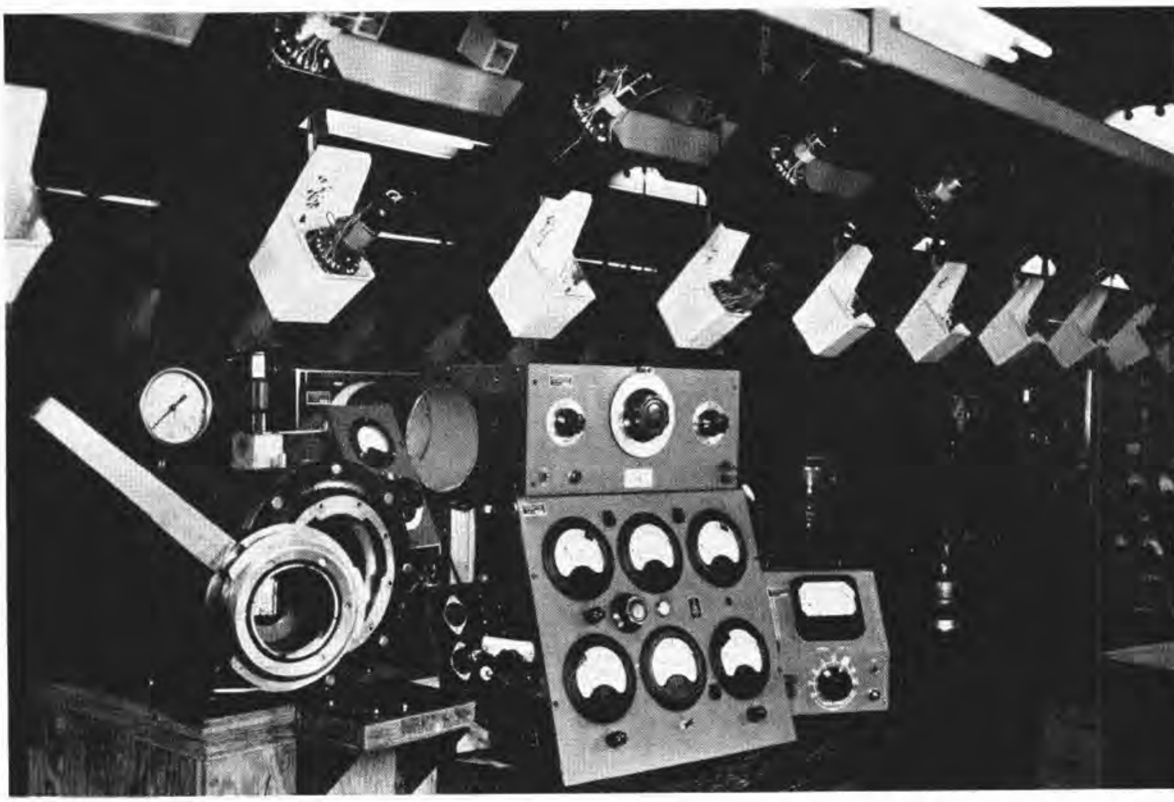


FIGURE 34. Final test position on production line. Fuzes are shown arriving at position via overhead conveyor belt (Emerson photograph).

Power supplies made by outside suppliers were given an incoming inspection at the plant of the principal contractor, even though the unit had been checked as satisfactory by the original manufacturer. Units were checked for A voltage, B voltage, and C voltage at rated loads. They were also checked to observe voltage regulation (of the power supply) over a specified speed range. Most manufacturers used an oscilloscope connected across the high-voltage output which served in some instances as a visual indication of erratic behavior which would not otherwise have been detected.

In the minds of some manufacturers was a well-defined suspicion that power supplies were a source of noise and several manufacturers had under way at the end of the production program the design of equipment intended to segregate these noisy power supplies. Most of these devices took the form of a transient detector built around conventional thyratron circuits, a noisy unit being indicated by either a visual or audible signal.

The final acceptance test given completed fuzes was most complete. The acceptance or rejection of the unit was based on measurements of the following values: (1) carrier fre-

quency, (2) diode voltage or grid voltage, depending on the type of unit, (3) millivolts to fire at peak audio frequency, (4) peak audio frequency, (5) A voltage, (6) B voltage, (7) C voltage, and (8) effective critical voltage of the thyratron.

The last criterion (effective critical voltage) was determined by establishing a fixed bias on the thyratron grid by means of the special circuits described in detail in Chapter 7 and running the unit over a specified range of speeds. If the unit fired during this run, the bias voltage was raised a fixed increment and the speed run repeated. Units which required a holding voltage greater than a specified value to prevent firing over the established speed range were rejected for noise.

Most manufacturers maintained a rework department staffed by technicians familiar with the operation and circuits of the fuzes and various subassemblies. Subassemblies or completed units rejected at the various test positions were shunted to this rework department, diagnosed, and repaired if the repair job was deemed to be economically feasible.

The apparatus used at the various test positions varied in slight details from manufacturer to manufacturer, although basically the circuit arrangements were the same. Some manufacturers went the limit in designing ingenious holding and connecting fixtures to expedite testing. Much use was made of air clamping devices and multiple contact fixtures wherein all connections were made to a fuze or power supply simply by depressing one lever. It is a well-known fact that no tool and fixture designer likes to copy completely the design used in another plant, and as a consequence the variations in methods of accomplishing the same end result were very interesting to observe. Since the design of holding fixtures and the like for fuze production presents no problems that have not been met in the manufacture of other electronic equipment, a complete description of the devices does not seem to be in order.

6.8 PRODUCTION ACHIEVEMENT

The following information, taken from reports from some of the major manufacturers involved, shows the magnitude of the production achieved.

Manufacturer*	Total fuzes produced	Rate per month at peak of operations	Number of production employees involved
A	315,000	52,800	1,050
B	247,138	40,418	883
C	255,996	39,600	1,000–1,800

* Manufacturer A made the complete fuze in the plant, including the power supply. Manufacturers B and C bought power supplies from outside sources.

Figures are available from only one manufacturer of power supply assemblies. They show a total of 490,150 power supplies made with production reaching a peak of 60,000 per month with 350 production employees.

Chapter 7

LABORATORY TESTING OF FUZES[a]

7.1 INTRODUCTION

For the purpose of expediting design engineering and production control, laboratory tests were required to obtain pertinent performance data. These tests and associated equipment are described in detail in this chapter.

The general outline of preceding chapters in which the principal performance characteristics and production problems were discussed will be followed in this chapter. A description of tests on the radio- and audio-frequency sections will be followed by a discussion of tests on components and other relevant tests. In addition, a brief outline of the tests used in a typical quality control laboratory, and an outline of tests used in a typical pilot line are included. As will be noted, the quality control test line is in general the reverse of the pilot line. This is obvious in that a quality control laboratory receives a completely assembled fuze, while a production line starts with components and ends up with a completely assembled fuze.

The emphasis of this chapter will be on the general principles involved while testing, omitting the theoretical discussion, since this is covered in Chapters 2 and 3. It should be pointed out that Chapters 2, 3, and 4 also include discussion of tests not mentioned here because such tests were related to development problems rather than the testing of finished fuzes.

The preferred laboratory testing procedure was to evaluate the performance of the separate sections of the fuze, i.e., r-f, audio, detonator circuit, and power supply, rather than to attempt to devise an overall performance test. The reasons for this approach were as follows: Fuze failure can occur from inferior or substandard performance from any of the various sections of the fuze. Testing each section separately for conformance to requirements insured reasonably good performance for the complete fuze. If overall tests were used, inferior performance of one section might be compensated, and hence masked by extra sensitive performance of another section. For example, a fuze which has an insensitive r-f section and a high-gain amplifier will fire the thyratron with a normal signal, since one section compensates for the other. If a section is unusually sensitive, the fuze may tend to become unstable and hence the probability for malfunctions of the fuze is greatly increased by a part which is out of tolerance.

Numerous attempts were made to devise an overall test but none of them appeared to offer the same assurance that fuzes would perform as reliably in the field as when the individual sections of the fuze were tested.

In designing test equipment, there were certain practical considerations to be taken into account. From the standpoint of production, equipment had to be designed to provide a maximum of economy in time, effort, and materials, yet give the required accuracy and ease of operation. The length of time the unit or subassembly was under test had to be as short as possible to conserve the life of component parts, such as tubes, bearings, and gear trains. Accuracy of the meters and other indicators of the test equipment had to be kept as high as possible by frequent calibration against suitable standards and adequate compensation for humidity and temperature variations.

7.2 TESTS ON THE R-F SECTION

7.2.1 Measurements Required

There are three kinds of r-f assemblies to be tested: *oscillator diode* [OD], *reaction grid detector* [RGD], and *power oscillating detector* [POD]. The parameters which determine the performance of these assemblies are diode voltage (for oscillator-diode units only), oscillator

[a] This chapter was prepared by Thomas C. Bagg and Paul J. Martin of the Ordnance Development Division of the National Bureau of Standards.

grid voltage, plate current, and carrier frequency.

As shown in Chapter 3, these parameters vary because of variations in radiation resistance upon approach to the target. However, certain of these parameter variations are more significant for each fuze type, that is, diode voltage for diode detectors, oscillator grid voltage for reaction grid detectors, and plate current for power oscillating detectors. It should be remembered, however, that all these parameters and carrier frequency are interrelated. It is therefore necessary to measure not only the steady-state values of these parameters but also the rate of change with load of the significant parameter for each fuze type. Such a measurement is an indication of the r-f sensitivity. Further, this section must be checked for stability when operating under extreme conditions of loading and supply voltages, since instability will produce a malfunction.

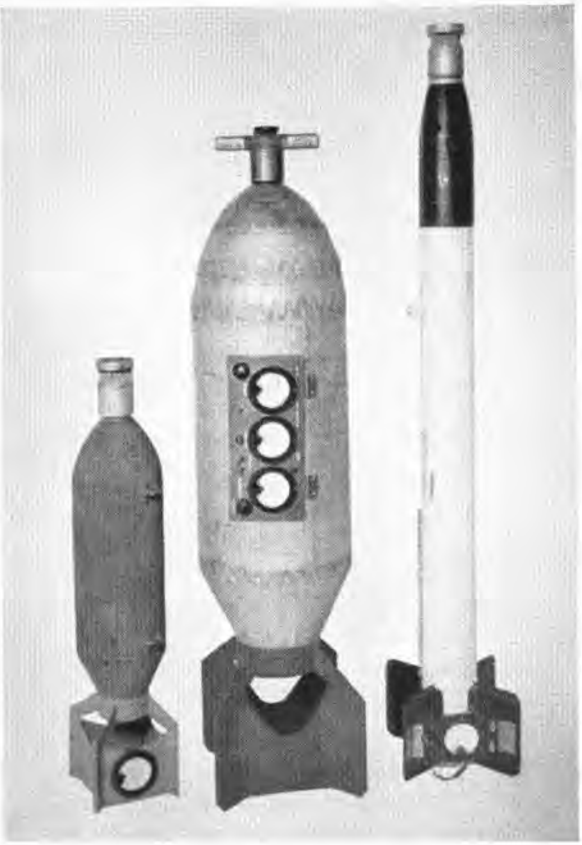


FIGURE 1. Reference vehicles for testing proximity fuzes. These represent, from left to right, M-30 bomb, M-64 bomb, and 5-in. AR rocket.

The preceding statements apply to measurements on the r-f subassembly. When measurements were made on the completed fuzes, it was necessary to have the r-f section operate under proper conditions of loading. The methods by which these conditions were obtained in the final test position are also discussed here.

7.2.2 Loading Requirements

The load presented to a fuze is composed of resistive and reactive components which are dependent upon the dimensions of the missile and the frequency of the oscillator. The radio frequency used is that which will give the required sensitivity and stability of the fuze for the missile or missiles on which it is to be used.

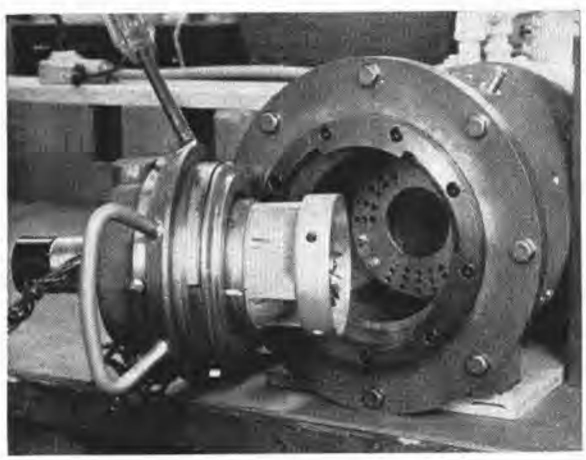


FIGURE 2. Final test chamber for ring-type fuzes.

Since it is inconvenient to measure the parameters which determine performance on actual missiles in free space, some form of laboratory test equipment had to be designed which would give accurate values of these parameters under simulated operating conditions.

To insure proper operation, free-space loading conditions were used as the basis, or reference point, for all laboratory measurements. As pointed out in Chapters 2 and 3, there was an optimum frequency for each missile which would give the required sensitivity, but, since

most of the fuzes had to operate on more than one missile, a compromise on frequency was made and a typical, or reference, missile chosen for test purposes. The following table gives the reference missile chosen for each fuze type.[15, 16, 39]

Class of projectile	Frequency, fuze type	Reference missile
Bomb	Brown frequency, ring-type	M-30
Bomb	White frequency, ring-type and all bar-type fuzes	M-64
Aircraft rocket	Brown frequency, ring-type and miniature rocket fuzes	5-in. AR
Aircraft rocket	T-5 and T-6	M-9
Mortar	All-frequency mortar fuzes	M-43C

For convenience in calibrating laboratory equipment, mockups of the missile which could

FIGURE 3. Compensated loading resistor on ring-type fuze.

be easily suspended in free space were made containing batteries and meters (see Figure 1).

To simplify testing further and to facilitate correlation of the equipment in the various laboratories, a load resistance was chosen to represent approximately the free-space load (see Section 2.7).[3, 20] The value chosen represented a slightly lighter load than the free-space load because under light loading unstable units were more readily detected.

In OD units, the reactive component of the load, however, had to duplicate that of free space, since any reactive load across the antenna not only changed the value of the parameters[14] but changed the operating point of the oscillator (or diode circuit) in such a manner as to reduce the r-f sensitivity. For example, 1 $\mu\mu$f of additional capacity across the nose cap of a diode detector-type fuze reduced the voltage by about 8 per cent, resulting in a reduction in sensitivity of approximately 16 per cent. The reactive component of the load was not critical in RGD units (see Sections 3.1.1 and 3.1.2).

7.2.3 Shielding

In order to prevent interaction between fuzes or the influence of nearby objects in the radiation field, it was necessary to shield the fuze during tests. The type of shield used for T-5 testing was a 16-in. plate placed behind the fuze in such a manner as to present the same capacity as the missile.[48] The important feature of this type of shield was that it unloaded the oscillator without detuning the diode circuit, but, on the other hand, it was not an infinite plane and r-f voltages were induced in adjacent test apparatus.

Completely enclosing shields were used for testing generator-powered fuzes. The excess capacitance loading produced by the shield was neutralized by inductive compensation.[24] For tests on the r-f subassemblies of these fuzes, the shields were usually 2-ft cubical metal-lined boxes. For tests on the completed ring-type fuze, where tuning and sensitivity measurements were not made, it was found more convenient to use a small but very heavy all-metal chamber (see Figure 2).

7.2.4 Loading Devices

Since the shield unloaded the oscillator, a resistive load was necessary to secure proper operating data. The dummy load developed for

T-5 tests consisted of an Aquadag (colloidal suspension of carbon) line drawn on Scotch tape and placed across the antenna insulator.[5, 48] A similar device was used for loading bar-type fuzes. This was Uskon cloth, a commercial product of 377 ohms per square, which was satisfactory when properly located in the 2-ft shield box.[51]

It was found possible to obtain the required resistance and reactance loading by the use of a resistance-capacitance-inductance parallel network loosely coupled to the fuze.[49] In some instances, a diode rectifier and tuning indicator were included.[13] When this network was tuned to resonance, it furnished only the resistive component of the load,[20] while the reactive component of the load was adjusted by the coupling. The position or coupling of the loading device relative to the fuze was determined by trial and error to duplicate free-space loading conditions.

For use in the 2-ft shield box, an inductance was wound on an ultra-high-frequency resistor to compensate for capacity excesses introduced by the box and resistor. Such a compensated resistor[24] consisted of an IRC ultra-high-frequency ceramic resistor upon which was wound a coil whose distributed inductance and capacitance was sufficient to tune out the unwanted portion of capacitance introduced by the shield and resistor. Such a resistor is illustrated in Figure 3. A modification of this type of load was used by one manufacturer when they used resistance wire to wind the inductance.

These compensated resistors provided the proper compensation throughout the frequency band used, since their reactance variations with frequency followed those of most fuzes and bombs. The usable frequency range of the compensated resistor for T-30 fuzes was very narrow. Because the rocket on which T-30's were used was long and thin compared to bombs, its free-space reactance variation with frequency was in the opposite direction.[39]

In the final test position, measurements were made of the overall stability of the fuze to random noise. It was particularly important that the loading introduce no errors in the measurements. Errors could be introduced in two ways: (1) vibration of the load caused by high-speed rotation of the generator, and (2) increased FM noise in the oscillator due to a low LC ratio

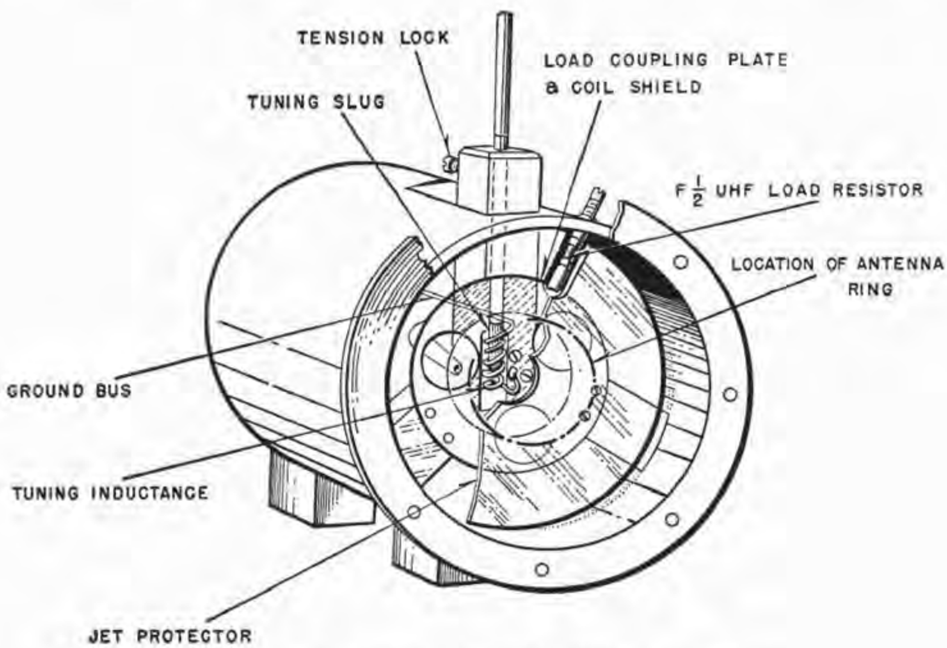


FIGURE 4. Inductively tuned load for OD ring-type fuzes.

[redacted]

in the inductive load.[17,45] In order to increase the LC ratio of the load (already low due to the presence of the enclosure), tuning was accomplished by a variable shunt inductance rather than with an added variable capacitance and fixed inductance. Coupling to the load in the test chamber was first made through a ring which fitted around the antenna of the fuze. This method of coupling was replaced by a disk in front of the fuze in order to reduce the capacity of the load and to reduce inductive coupling between the oscillator and loading coils[21,43] (see Figure 4).

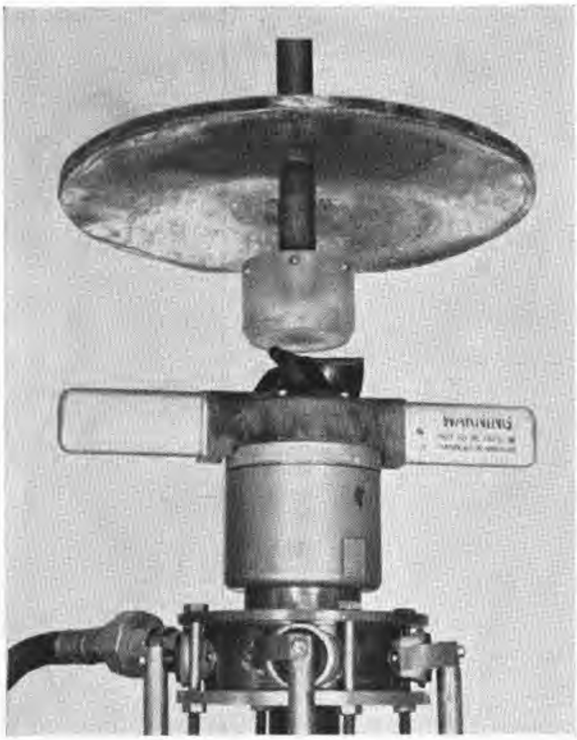


FIGURE 5. Disk load for bar-type fuzes. Central tube and nozzle carries compressed air to drive windmill.

For RGD units, no variable tuning was necessary, so that the means of loading simply became a compensated resistor connected between the coupling disk and the chamber.

The test fixture for bar-type fuzes was a 2-ft shield box with the fuze mounted on a standoff to reduce capacity loading across the dipoles. The length of the standoff was important in that it became a resonant line at particular frequencies, lengths, and diameters.[25,36] In the 2-ft box, a 3½-in. pipe 7 in. long gave no spurious effects. The load consisted of either a sheet of Uskon cloth alongside the dipoles (Figure 37 of this chapter) or a disk of Uskon cloth in front of the dipoles (Figure 5). The disk did not require orientation of the dipoles. To prevent contamination of the load by oil, sludge, etc., the cloth was covered by a thin sheet of Lucite or celluloid. A test chamber for laboratory testing of complete fuzes with transverse antennas was designed for use as a noise reference fixture to evaluate the production test boxes (Figure 6). This chamber used a tuned resistance load similar to that described above.[43]

Some difficulty was experienced in correlating different test positions because of changes in r-f resistance with frequency. This variation was greatest with high-value resistors.[55] To overcome this difficulty a set of resistors was arbitrarily selected as reference standards.

For units which had normal radiation resistances of 100,000 ohms or greater, it was found desirable and convenient to use no resistive component other than that in the tuning element of the load. This type of loading was used with T-51, T-82, T-132, and T-171 fuzes.

FIGURE 6. Final test chamber for bar-type fuzes.

Several experimental test fixtures were constructed which used a quarter-wave line to obtain the r-f load. Westinghouse (Baltimore) used such a device for their T-5 fuzes. Philco also used it for their T-50 production. Some

work was done at the National Bureau of Standards on this type of loading, but not with particularly satisfying results except in the case of a device for the measurement of absolute sensi-

FIGURE 7. Resistor for determining sensitivity of bar-type fuzes.

tivity of an end-fed axially excited fuze (see Section 2.12).

Loads based on parallel transmission lines were also experimented with but not used to any great extent.

7.2.5 Sensitivity Test

The most direct method of measuring r-f sensitivity is a pole test as described in Section 2.12.

This test was the only practical means of determining the sensitivity of very early fuzes, because the close coupling between the oscillator and diode circuits would throw the oscillator into unstable operation when the fuze was unloaded to obtain V_∞ for the sensitivity formula [equation (4), Chapter 3].

However, for production testing, this was impractical and was used only as the standard for free-space loading and absolute sensitivity measurements.

The use of compensated resistors in the 2-ft shield box gave rapid and sufficiently accurate data for sensitivity determinations. For such determinations, the diode voltage, grid voltage, or plate current was plotted against the natural logarithm of the load resistance and the sensitivity obtained from the formulas [equations (4) and (6), Chapter 3]

$$S = \frac{dV}{d \ln R},$$

or

$$S = E_B \left(\frac{I}{I_\infty} - 1 \right).$$

Figures 3 and 7 illustrate loading resistors used in sensitivity determinations. For certain units where the normal load was in the linear portion of the loading curve (see Figure 7, Chapter 3), only two points, or resistors, were necessary to determine the sensitivity. For fuzes which had very high load resistance, uncompensated resistors of 100,000 ohms and infinity were used where [equation (16), Chapter 3]

$$S = V_\infty - V.$$

It was first thought unimportant to inductively compensate sensitivity resistors for RGD units,[44] but it was found desirable to do so in order to prevent shifting of the operating point of the oscillator.

7.2.6 Stability Test

In order to test fuzes for r-f stability, the first test used for T-5 fuzes[5] consisted of decreasing the r-f loading and tuning the unit through resonance. If no discontinuities were observed in diode voltage, plate current, or carrier frequency, the fuze was considered stable. Other indications of instability were self-blocking (squegging)[5] which was noted by the presence of discrete side bands. A more satisfactory stability test was devised where an alternating plate voltage was applied to the oscillator, which caused it to go in and out of oscillation. The plate voltage was applied to the horizontal plates of an oscilloscope, while the oscillator grid voltage was applied to the vertical plates; this showed the grid voltage as a function of plate voltage and readily disclosed any tendencies toward instability.

[redacted]

7.2.7 Carrier Frequency

Carrier frequencies were measured by loosely coupled absorption-type wavemeters or ultra-high-frequency receivers. Care was required when using superheterodyne receivers to insure that the true frequency was read and not that of the image or some other spurious responses. To maintain accurate calibrations, harmonics of a standard 5-mc oscillator were used. These oscillators were periodically checked against WWV, the standard frequency station of the National Bureau of Standards.

7.3 AUDIO TESTS

7.3.1 Measurements Required

The function of the audio portion of the fuze is to select the proper signal and amplify it sufficiently to actuate the trigger circuit (thyratron). Laboratory tests required were therefore those necessary to determine the gain-frequency characteristic as well as the peak gain. Gain, as such, was not measured. Instead, the input signal to the amplifier (in rms millivolts) required to fire the thyratron was used to indicate amplifier quality. Every effort was made to insure that test conditions were the same as those which existed when the fuze was in operation. Hence, if the oscillator were disconnected or blocked, the impedance which the amplifier saw when looking back into the oscillator would be altered and normal signals such as filament hum coming from the oscillator would be distorted. Any indicating device connected to the amplifier output, i.e., thyratron grid, was such that it did not affect the amplifier characteristics. A high-impedance cathode follower was usually used for coupling test instruments to the amplifier output. Any connection to the thyratron plate had to be such that proper voltages were applied, since the thyratron critical voltage was a function of its plate voltage. Also, any firing indicator circuits had to have current limiters so as not to weaken or destroy the thyratron.

7.3.2 Input Circuits

It was necessary to use various types of input circuits to meet the needs of different units. With oscillator-diode units, the diode was blocked while making amplifier measurements to eliminate noise developed in the oscillator.[1] This was easily done by applying a negative voltage to the diode and amplifier test lead. This voltage had to be greater than the peak r-f voltage developed in the diode circuit to compensate for the rise in r-f voltage occurring when the diode was blocked and made non-conducting. Blocking the diode changed the impedance which the amplifier saw when look-

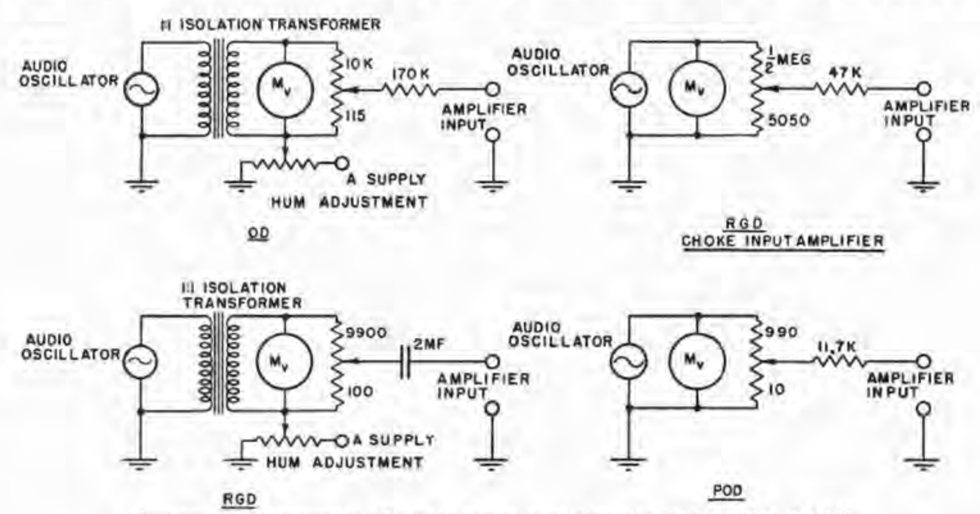


FIGURE 8. Schematic of audio input test circuits (OD, RGD, POD).

ing back toward the oscillator.[41] To correct for this change of impedance, a resistor of 170,000 ohms was used in series with the blocking battery[46] and source of audio voltage. This audio voltage was obtained from a commercial audio oscillator through a voltage divider in order to permit metering of the voltage by rectifier-type voltmeters. Typical audio input circuits are shown in Figure 8.

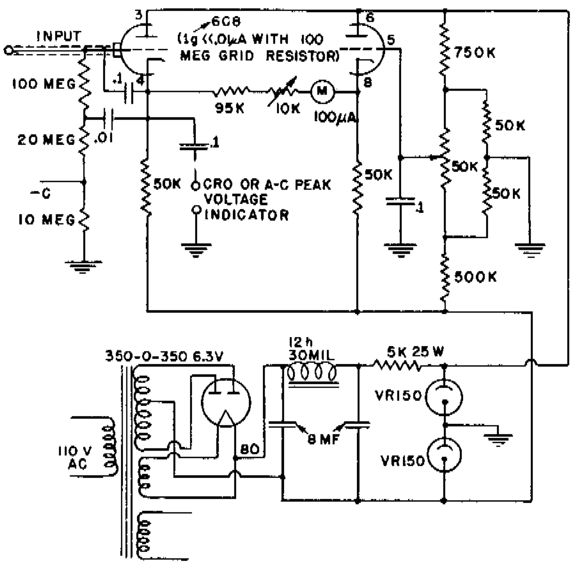


FIGURE 9. Schematic of cathode follower and d-c VTVM (used on amplifier output).

For testing fuzes which contained no diode, the r-f signals were eliminated by either disconnecting the oscillator from the amplifier (which in some instances was inconvenient) or using a low-impedance by-pass between the oscillator and high-input impedance amplifier.[19] In the case of choke[51] or transformer input, it was necessary to use the first method and obtain the audio voltage through a circuit equivalent to the fuze oscillator.

As pointed out previously, the filament hum present in the oscillator output due to an unbalanced filament supply had to be duplicated by a voltage injected with the test signal. This was done by raising the voltage divider above ground potential by the amount of hum voltage necessary to duplicate that present in the oscillator output. The phase of the hum so injected had to be within 10 degrees of that in the oscillator output. Care to maintain the normal value of filament hum appearing at the thyratron grid was also necessary in order to obtain proper effective critical voltage for the thyratron (see Section 3.3.5).[10, 47]

7.3.3 Output Circuits

Since the amplifier load consisted of an RC network which controlled the high-frequency cutoff and phase of the feedback voltage, it was

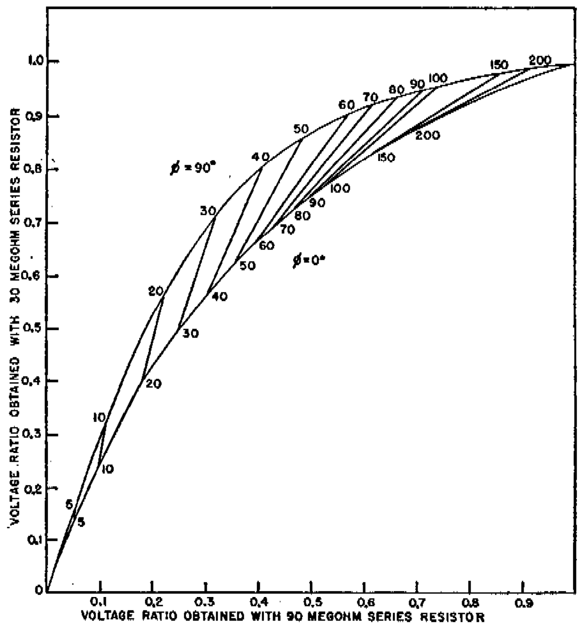


FIGURE 10. Cathode follower impedance chart. Measurement of cathode follower input impedance by use of accurate 30- and 90-megohm resistors.

Apply a convenient voltage (10 volts, 200 c) directly to cathode follower input lead and observe output E_1 on vacuum-tube voltmeter. Apply same voltage through series resistor of 30 megohms and note reading E_2 (30). Repeat foregoing step with 90-megohm resistor and note reading E_2 (90). Form the ratios

$$\frac{E_2\ (30)}{E_1} \text{ and } \frac{E_2\ (90)}{E_1}.$$

Locate point on graph corresponding to two ratios and find impedance by interpolating between curves of constant impedance.

essential that any test instrument connected to the amplifier output would in no way alter the amplifier output impedance. For this purpose, cathode followers were used for coupling to commercial voltage indicators, such as voltmeters, oscilloscopes, or magic-eye tubes. The

impedance of the cathode followers used was of the order of 50 megohms at 200 c and 12 megohms at 1,000 c. Values in excess of 40 megohms at 200 c and 10 megohms at 1,000 c caused negligible errors in the measurements and these values were introduced as specification limits for acceptance testing.

Impedance losses in test leads between the amplifier and cathode follower due to capacity to ground frequently caused difficulty in meeting the specification limits. By using a shielded lead where the shield is connected to the cathode of the follower tube, this parallel impedance loss can be greatly reduced (see Figure 9). Figure 10 illustrates a method of rapidly determining the input impedance of the follower when the capacitive components of the lead and tube are considered.

7.3.4 Thyratron Tests

Effective Critical Voltage. The highest negative grid biasing voltage which will fire the thyratron is called the critical voltage. (The critical voltage is, of course, different for a-c operation of the thyratron filament than for d-c.) The term *normal critical voltage* was applied to the highest negative biasing voltage which would fire the thyratron in the operating fuze assembly with microphonic noise from the oscillator blocked. The usual procedure for measuring normal critical voltage was to block the oscillator and inject (at the amplifier input) a ripple signal equivalent in magnitude and phase to that ripple from the oscillator filament. The term *effective critical voltage* was applied to the highest negative biasing voltage which would fire the thyratron when the fuze was completely operating, that is, when microphonic noise from the oscillator was passed on to the thyratron grid. In the generator-powered fuzes, these measurements were made with the generator running (driven by an air jet directed on the vanes) so that microphonics induced by the rotating system would show up as a change in the effective bias of the thyratron.

In making measurements of effective critical voltage, it was not possible just to reduce the applied bias on the thyratron, since this bias was also applied (through a voltage divider) to the pentode.[11] Such procedure would have caused changes in amplification resulting in other-than-normal hum voltage at the thyratron grid. A high-impedance positive voltage source was therefore applied directly to the thyratron grid along with a high-impedance voltmeter. It was also necessary in all of the equipment to insure that there was very little coupling between input and output test circuits, since any such coupling would appear as paralleling the gain-control condenser (C8 in Figure 26 of Chapter 3) and seriously affect gain adjustment or amplifier performance.

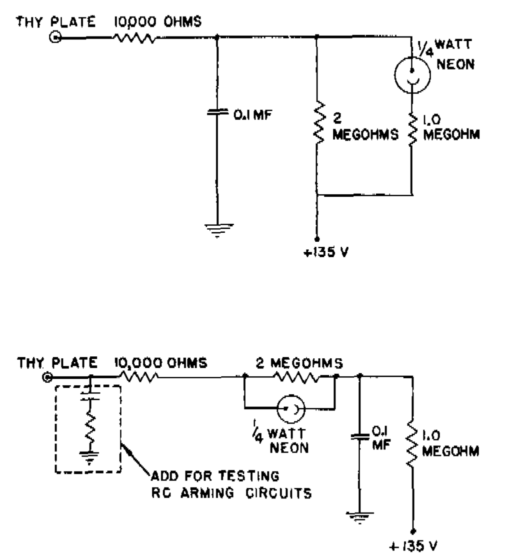


FIGURE 11. Firing indicator for thyratrons: for tube and unit testing, except units with RC arming (top); brighter flash, satisfactory only when a-c signal is used on thyratron grid (bottom).

A type test (later a production test) was required to determine if the actual bias at the thyratron grid was approximately equal to the applied C bias. Leakages through the output coupling condenser to the plate supply, through the potting compound to ground, and along the component surfaces, tended to reduce the bias at the thyratron grid. Such leakages, if present, caused unstable and erratic performance.

Firing Indicator. The most convenient firing indicator consisted of a neon bulb and RC network where the neon fired either on discharge

or charge of a condenser (Figure 11). Such a circuit was advantageous in that it was simple, unharmful to the thyratron, and quenched so quickly that the thyratron would recover for rapid testing. Other types of firing indicators were developed and used, ranging from a simple lock-in circuit which remained operative once the thyratron fired, to circuits which rang bells, flashed lights, etc.

Routine tests for passing surge currents through the thyratron were frequently discussed but seldom used outside the laboratory since the failure of a thyratron in a fuze to pass ample current was rarely reported.

7.4 STABILITY TESTS

7.4.1 Purpose of Stability Tests

A major cause of malfunctioning of fuzes in field and service tests was noise or microphonics in the electronic assemblies. Accordingly, considerable effort was made to devise laboratory tests which would show up or sort out noisy units. Since noise was usually produced by the vibration of loose or weak parts, either in the circuit or in the tubes, the testing methods employed shaking or shocking techniques. The ability of a fuze to withstand vibration was considered as a measure of its stability.

Various methods were used to indicate the stability of a fuze under vibration: (1) the peak noise voltage at the thyratron grid, (2) the highest negative bias applied to the thyratron grid, which would cause firing, i.e., effective critical voltage under the selected conditions of vibration, and (3) the difference between the effective critical voltage and the thyratron bias voltage, i.e., noise margin.

7.4.2 Methods of Producing Vibration or Shock

Laboratory methods of inducing vibration in fuzes attempted to duplicate (in a crude way) the vibrations experienced by the fuze on a missile in flight. It is well known that air turbulence and fin flutter produce intensive vibration in missiles and these, of course, will be transmitted to the fuze.

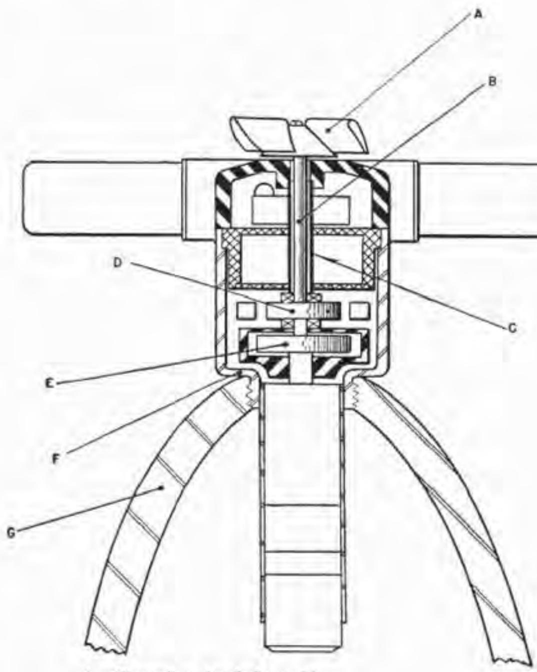
The first vibration or shock method employed to select stable fuzes was the simple expedient of striking the fuze (or rather a test missile in which it was mounted) with a club. This method was strictly qualitative, but field scores were greatly improved by discarding fuzes which showed excessive noise signals when hit with the club.

The club test for fuze stability was refined by producing the shock with a calibrated pendulum and employing a standard mount for the fuze.[5] Although the shock test produced little reliable quantitative data, it did lead to considerable improvement in tube design and to improvements in the technique of anchoring components in the r-f section. All T-5 fuzes were subjected to the pendulum shock test.

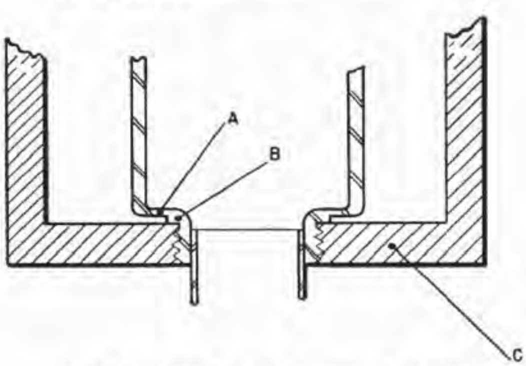
With the advent of generator-powered fuzes, an additional source of vibrational energy appeared through slight unbalance of the high-speed rotating system. Analysis showed that such an unbalanced rotating system was the best microphonics testing device, because it produced exciting forces in all directions in a plane, because the entire range of exciting frequencies could be easily covered, and because the exciting forces were maintained long enough to build up peak amplitudes at resonant frequencies.[9, 23] The weaknesses of the shock test were the presence of directional effects and the inability of a single shock to build up vibration amplitudes at resonant frequencies.

When a fuze was mounted in its adapter or encasing can on a bomb, unbalance in the rotating system produced vibrations of large amplitudes because the bottom of the adapter acted as a resonant diaphragm in the frequency range of 20,000 to 35,000 rpm (see Figure 12). This method of producing vibration was used in the final test fixture where an adapter was tightly screwed into a massive test chamber. A shoulder of at least 0.010 in. was cut on the bottom of the adapter to simulate mounting on a bomb ogive (see Figure 12). To permit uniform testing and to compensate for

adapter differences, the bottoms of the adapters were cut so that resonance occurred at approximately 25,000 rpm.



A Propeller (unbalanced)
B Coupling shaft (off center)
C Shaft shield
D Generator rotor (unbalanced)
E Gear train (binding)
F Adapter can bottom (resonant diaphragm)
G Ogive of bomb



A Adapter can bottom (resonant diaphragm)
B Shoulder greater 0.010 in.
C Test fixture

FIGURE 12. Resonant mountings: fuze on bomb illustrating pertinent vibration elements (top); test adapter (bottom).

Numerous difficulties were encountered in calibrating such a mount. A study of adapters showed that the mechanical properties of the diaphragm were not uniform. This led to different amplitudes and changes in frequency during use, which were probably caused by cold working of the metal and fatigue. In addition, an analysis of such a resonant mount in a test chamber revealed numerous uncontrollable variables.[37] As a temporary expedient, an assembly containing a rotating system of known unbalance was used to calibrate test fixtures. Such assemblies were called reference vibration heads and are shown in Figure 13.

As propeller balancing techniques improved, self-excited resonant vibration systems lost their ability to test adequately stability and other methods were sought. One system proposed was the addition of a known unbalance to the propeller and the use of a soft mount to overcome the difficulties inherent in a resonant system. This system appeared to have a number of advantages for obtaining a qualitative measure of unit stability.[37] Development of this method was not completed at the end of World War II.

FIGURE 13. Reference vibration heads used to calibrate vibration response of test fixtures.

Many types of external vibrators (in contrast to the internal source of vibration in the fuze's rotating system) were designed and tried. The first, the rotary vibrator (Figure 14), followed the principle mentioned above, that is, an unbalanced mass was rotated at high speeds.[9] The vibrator housing was supported on

a soft mount with the fuze to be tested on the other end. Bearing failure, poor high-speed motors, and the small mass which such a system could vibrate, limited the use of the rotary vibrator to components (particularly tubes), head assemblies, and miniature fuzes.

Several models of a vibrator using a precessing ring operated with some success (Figure 15). One contractor turned the unbalanced turbine 90 degrees, getting vibration in a vertical plane. Models in which a ball was driven at high speed around a race showed promise[38] (Figure 16). Another device which proved unsatisfactory consisted of four diaphragms 90 degrees apart around the unit mount, the diaphragms being actuated by a rotating valve on a high-pressure air line. The impedance of the air supply lines was so great that very little energy was delivered to the unit, and the scheme was also unsatisfactory at high frequencies. None of these vibrators was developed for production testing by the end of World War II.

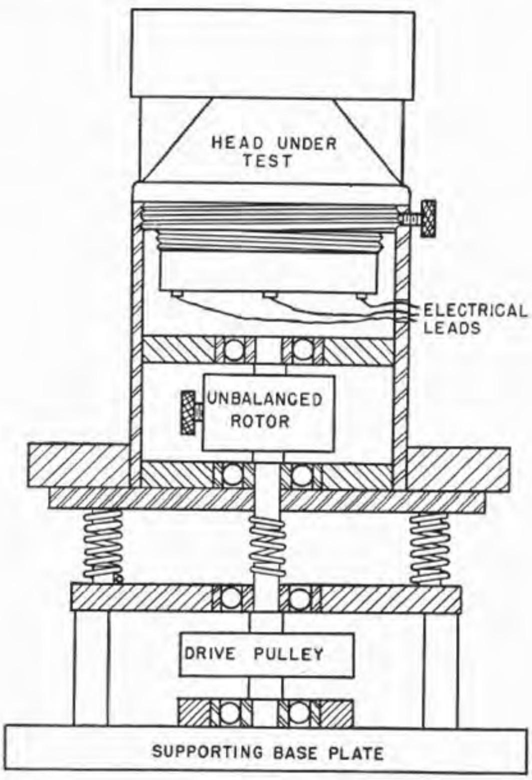


FIGURE 14A. Rotary vibrator. Schematic section of head assembly mounted on mechanically driven vibrators.

7.4.3 Other Noise Sources

In addition to noises caused by microphonics, there were other sources of noise in the fuze which had to be eliminated (see Section 3.1.5). In the later part of T-5 production, extremely

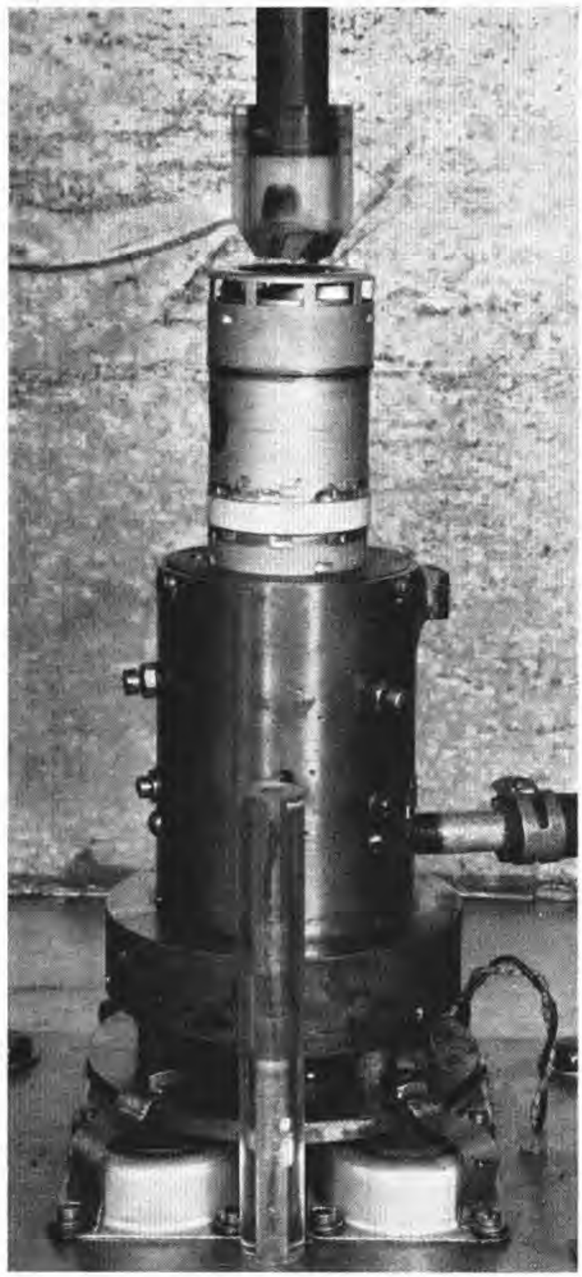


FIGURE 14B. Miniature fuze mounted on air-driven vibrator; operates on principles illustrated in Figure 14A where air turbine is unbalanced.

sharp high-voltage pulses were observed on a long-persistent screen oscilloscope. Improvements in tubes and changes in operating point of the oscillator apparently eliminated these pulses and no further study was necessary. Rotational frequency noise, that is, noise associated with the speed of the rotating system, was caused by eccentric coupling shafts rotating in

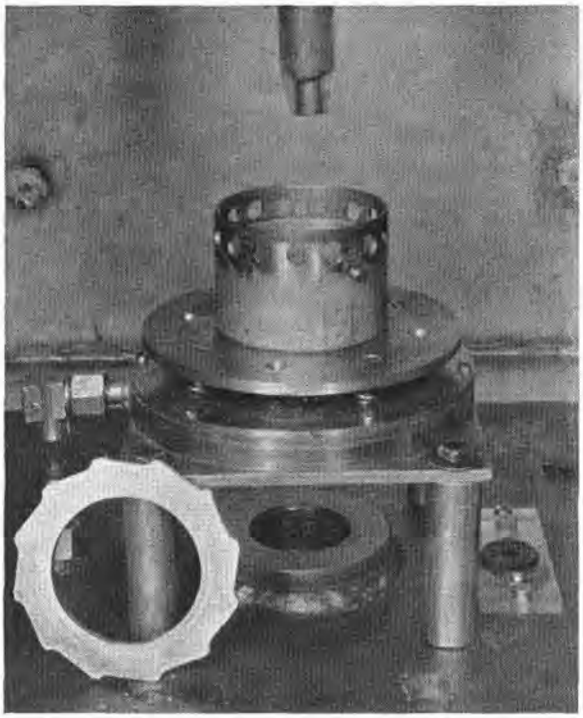


FIGURE 15. Precessing ring vibrator.

the r-f field, gear trains which had binding action at a certain spot, etc. The power supply was an occasional strong source of rotational noise, particularly when radio frequency was present in the generator and gear train housing.

7.5 COMPONENT TESTING

7.5.1 Introduction

Proper performance of the major subassemblies of the fuzes depended on the careful selection of the various components. Close tolerances were set on the performance requirements of the subassemblies and these could only be met in turn by setting close tolerances on the components. This section outlines the types of tests which were used to select the most important components. Details of the tests are generally not given; instead, reference is made to source material in the bibliography.

7.5.2 Tube Testing

Tubes were probably the most critical of all components both from performance and manufacturing viewpoints. Proper performance of the oscillator was based primarily on the characteristics of the triode. The required response of the amplifier was intimately related to prop-

FIGURE 16. Ball race vibrator.

erties of the pentode, while the reliability of the detonator circuit was no better than the dependability of the thyratron. Because the tubes were tiny, complex, and difficult to manufacture, it was necessary to work out careful performance tests in order to insure that the tubes would be satisfactory.[6, 35, 53] Here we will confine the discussion primarily to a listing of the properties which were measured.

As indicated in Section 7.4, one of the most

TABLE 1. Summary of diode tests.[6, 35]

Name of test	Purpose of test	Limits and requirements (NDRC specifications, Aug. 1, 1944)
Filament current*	To insure that filament current will be within limits for satisfactory operation.	Filament current shall be at least 60 ma d-c, and not exceed 80 ma d-c, with 0.6 v d-c applied directly to filament.
Leakage test*	To measure reverse d-c current through leakage paths in the tube.	Leakage current shall not be greater than 3 μa d-c under operating conditions.
Self-noise test*	To measure a-c component of leakage current mentioned above.	Maximum peak self-noise shall not exceed 0.1 mv.
Rectified current test*	To measure the diode efficiency, that is, the ratio of the d-c voltage developed across a specified load to the peak input voltage.	Diode current shall be at least 30 μa d-c with 30 v rms, 60 c, input.
Centrifuge†	To determine ability to withstand setback encountered in rocket fuze application.	To pass critical tests after acceleration of 2,500g.
Operation†	To insure adequate life expectancy.	After operation for 15 min, the rectified current shall not differ more than 10% from the value at beginning of operation.

* These tests were given to all tubes (100% tests).
† These tests were given to representative samples from each lot of tubes (sampling tests).

TABLE 2. Summary of triode tests.[6, 53]

Name of test	Purpose of test	Limits and requirements (Ordnance Dept. specification, July 25, 1945)
Heater current* (filament current)	To insure that filament current will be within limits for satisfactory operation.	Filament current shall be between 0.230 amp d-c and 0.150 amp d-c with applied voltage of 1.20 v d-c.
Gas test*	To detect presence of gas which creates fluctuations of plate current and internal impedance.	Grid current must not exceed 2 μa d-c between 1 and 6 sec after application of test voltages.
Oscillation* (grid bias test)	To insure sufficient grid bias voltage can be developed to maintain uninterrupted oscillation.	Grid bias of not less than 22 v d-c must be self-developed with plate current of between 7 and 11 ma d-c for from 1 to 30 sec after application of test voltages.
Oscillation frequency test†	To insure that oscillator frequency controlled by interelectrode tube capacities will be held within proper limits.	Frequency of each tube must not differ by more than $\pm$5 mc from standardized value.
Self-noise†	To measure spontaneous noise within the tube.	Total instantaneous noise of tube at rest shall not exceed 0.01 v.
Microphonics*	To insure minimum noise voltage when tube is subjected to vibration.	The total instantaneous noise after amplification in a shaped amplifier (gain approx 100) shall not exceed 0.6 v when vibrated (0.012 in amplitude) at a frequency in the pass band of the amplifier.
Operation test†	To insure satisfactory oscillation performance after a period of operation in excess of the expected time for combined testing of the tube and the completed fuze.	After 15-min operation under specified conditions, oscillator grid bias must not differ by more than 20% from value noted prior to test.
Centrifuge†	To determine ability to withstand setback encountered in rocket and mortar fuze application.	Grid bias and plate current must not differ by more than 20% from values before centrifuging, 12,000g.

* These tests were given to all tubes (100% tests).
† These tests were given to representative samples from each lot of tubes (sampling tests).

[redacted]

important properties, particularly for the triode, was microphonic stability. This property was examined on tubes before they were built into fuzes. It was also examined, though indirectly, in stability tests on completed fuzes (see Section 7.4).

check a large percentage of the resistors and capacitors to obtain some idea of the effect of component variations upon fuze performance. The production line, however, did not require such information, but did find it necessary to check certain critical resistors and condensers

TABLE 3. Summary of pentode tests.[6, 53]

Name of test	Purpose of test	Limits and requirements (Ordnance Dept. specification, July 25, 1945)
Heater or filament current*	To insure that filament current will be within limits for satisfactory operation.	Filament current shall be between 0.072 amp d-c maximum and 0.052 amp d-c at 0.6 v d-c.
Voltage amplification*	To insure that voltage amplification of pentodes is sufficient.	Voltage amplification in a specified amplifier (no feedback) shall not be less than 90 nor greater than 120.
Noise* (microphonics)	To insure that pentodes used in fuzes are not excessively microphonic.	Total instantaneous noise, expressed as the maximum peak variation in the plate voltage caused by any single mechanical shock, shall not exceed 0.75 v when the tube is subjected to the proper test conditions.
Dynamic input impedance†	To insure that input impedance is sufficiently great.	The input impedance shall not be less than 10 megohms under operating conditions.
Plate resistance†	To insure that plate resistance is sufficiently great, since low plate resistance affects the phase shift of the feedback network.	The plate resistance while the tube is operating in the specified circuit shall be in the range 2.0 to 5.75 megohms.
Special (low) voltage amplification†	To insure that the amplifier would function properly with reduced voltages.	The voltage amplification when determined in the specified manner shall not be less than 75.
Operation test†	To insure satisfactory voltage amplification of the pentode after a period of operation in excess of the expected total time required for testing the tube and completed fuze.	After 15-min operation under specified conditions, voltage amplification must not differ by more than 10% from value noted prior to test.
Mechanical stability of elements† (centrifuge test)	To determine ability to withstand setback encountered in rocket and mortar fuze application.	To withstand acceleration of 12,000g under certain specified conditions, and 2,500g under other conditions. The value of voltage amplification after centrifuging shall not differ by more than 10 per cent of the value prior to centrifuging, and the noise after centrifuging shall not exceed 0.83 v peak.
Surface electric leakage†	To insure that surface leakage of the tube is not low enough to impair its operation.	The minimum electric resistance between the plate lead and all other leads shall be 25 megohms.

* These tests were given to all tubes (100% tests).
† These tests were given to representative samples from each lot of tubes (sampling tests).

A summary of the important tests on the various tubes is presented in Table 1 for diodes, Table 2 for triodes, Table 3 for pentodes, and Table 4 for thyratrons.

7.5.3 Resistors and Capacitors

It was necessary for pilot line production to maintain a high level of fuze performance. When such testing was required, ordinary commercial-type limit bridges were used, although several automatic sorting devices were proposed and tried. Special surge testers to determine the inductance of the cylindrically wound detonator-firing capacitor were developed in order to design more efficient noninduc-

TABLE 4. Summary of thyratron tests.[6, 53]

Name of test	Purpose of test	Limits and requirements (Ordnance Dept. specification, July 25, 1945)
Heater or filament current*	To insure that filament current will be within limits for satisfactory operation.	Filament current shall be between 0.100 amp d-c and 0.080 amp d-c at 1.2 v d-c.
Critical grid voltage*	To insure that critical grid bias is within proper limits, since this parameter is one which governs overall sensitivity.	The critical grid voltage shall be within the range —1.7 to —2.5 v d-c.
Grid circuit voltage drop*	To insure that there is no excessive leakage between the tube leads; such leakage tends to make the negative bias at the grid itself lower than the applied C bias.	The grid circuit voltage drop shall not exceed 0.40 v d-c.
Minimum surge*	To insure that the minimum peak discharge current passed by the thyratron will be sufficient to fire the electric detonator.	The peak plate current shall not be less than 5 amp.
Constancy of critical voltage†	To determine the effect of changes in supply voltages on the critical grid voltage.	Variation in the critical grid voltage with specified changes in heater and plate voltages shall not exceed 0.6 v d-c.
Operation test part 1, heater life†	To insure that the thyratron will not undergo any deterioration in operating characteristics after a period in excess of the expected time required for testing the tube and completed fuze.	The tube shall be electrically stable as evidenced by freedom from changes in critical grid voltage exceeding 0.40 v d-c after being operated for 15 min.
Part 2, repeated surge†	To insure that critical grid voltage does not change appreciably after the thyratron has been fired ten successive times.	The tube shall be electrically stable, as evidenced by repeated compliance with the minimum surge test, freedom from changes in critical grid voltage exceeding 20% of initial value and from changes in grid circuit voltage drop exceeding 0.20 v d-c, after operation for 15 min.
Mechanical stability of elements† (centrifuge)	To determine ability to withstand setback encountered in the rocket and mortar fuze application.	To withstand acceleration of 12,000g under certain specified conditions, and 2,500g under other conditions; after centrifuging the critical grid voltage shall not differ by more than 10% of precentrifuging value, the value of grid circuit voltage drop shall not differ by more than 0.15 v d-c from the precentrifuging value, and the minimum surge current shall be greater than 4.5 amp.
Internal electric leakage	To insure that electric leakage within the thyratron is not excessive.	The thyratron shall not pass more than 2.5 μa d-c when the control grid is tied to the plate and minus 135 v d-c applied.
Surface electric leakage†	To insure that surface electric leakage about the thyratron is not excessive.	The minimum electric resistance between the plate lead and all other leads shall be 25 megohms.

* These tests were performed on all tubes (100% tests).

† These tests were performed on representative samples from each lot of tubes (sampling tests).

tive condensers. The reader is referred to reference 32 for the background of component tests and specifications.

7.5.4 Coil Testing

In general, testing of oscillator coils consisted of visual inspection to insure that adequate cement had been applied and that the proper number of turns had been wound. However, for transverse antenna fuzes (T-51) a double coil was used. This double coil had to be tested for high-voltage shorts or breakdowns. Figure 17 shows a small test set which was used for breakdown testing of coils and condensers.

7.5.5 Rectifier Assemblies

Since the rectifier buttons used in the fuzes

were developed specifically for the fuzes, new production test equipment was required to make 100 per cent tests. This equipment was designed to measure the forward voltage drop and back current under specified conditions. In addition, a probe was developed which would apply the proper voltages and compression or contact force. Requirements for rectifier testing are given in Section 3.4.5.[33, 52]

FIGURE 17. High potential leakage tester. Double-wound coil for T-51 fuze is shown being tested for insulation between coils.

7.5.6 Chokes and Transformers

The small r-f filter choke was very delicate by virtue of the very fine wire coil. This fine wire would frequently be broken while bending the choke leads during assembly. A continuity test was, therefore, incorporated in the audio prepot test position as an oscillator functioning test. The audio chokes and transformers used in certain fuzes (T-51 and T-82) were frequently tested before assembly in mockup amplifiers to determine their resonant frequency. A mockup circuit was most satisfactory, since it gave direct comparison data and since direct inductance measurements of these particular chokes were difficult.

7.5.7 Propeller and Turbine Assemblies

As mentioned previously, every effort to eliminate vibration of the fuzes was made. One of the largest sources of vibration energy came from unbalanced rotating systems. Unbalanced propellers and off-center coupling shafts produced considerable vibration in the large fuzes, while dynamic unbalance of the turbine and generator rotor shook the miniature fuzes. Tests to determine unbalance were standard production line procedure and the methods are discussed in Sections 4.6 and 6.4.

7.5.8 Generators and Power Supply

In testing generators it was necessary to determine that the bearings ran smoothly and that the rotor would not break at high speeds. It was also necessary, of course, to see that the developed A and B voltages met specifications.[7, 34] Tests were made with the generator working into a mockup of a typical rectifier-filter section.

This mockup rectifier-filter section consisted of four half-wave vacuum-tube rectifiers with series resistors to match the forward resistance of an average rectifier assembly and a parallel resistor to match the average leakage resistance (see Figure 32).

Tests on completed power supplies were made while working into a typical load. Generators or power supplies not attached to fuzes were driven by air turbines or high-speed motors.

Adjustment of the A and B voltages developed by the generator was accomplished by overmagnetizing the rotor and demagnetizing to the proper amount while the generator was under test. Overmagnetization followed by partial demagnetization was found necessary to obtain stable magnets.[12]

Several successful demagnetizing schemes were used and one may be found in reference 42.

At this time it would be well to describe briefly the types of meters used in measuring A voltages. The waveform of the A voltage was not quite sinusoidal because of transformer action

[redacted]

between the A and B windings, which mixed a square wave voltage, caused by the rectifier load, and a sine wave voltage from the A winding which was under a resistive load. It was therefore necessary to measure its rms value as an indication of its effective, or heating power. Ordinary rms meters which used either a thermocouple, dynamometer movement, or moving vane were unsatisfactory for routine tests. The thermocouple meters were sensitive to ambient temperature variations, would respond to stray audio and r-f voltages, were very sensitive to overload, and in general were of such low impedance that they applied an additional indeterminate load on the power supply. The dynamometers had very low impedance, requiring power equal to or greater than the total generator output. The moving vane meters were extremely frequency dependent and very insensitive at frequencies greater than 500 c. A vacuum-tube voltmeter was developed for laboratory use but was unsatisfactory for routine testing. It was demonstrated that the waveform between generators of a given type were sufficiently uniform to allow the use of rectifier-type meters, provided these meters were frequently calibrated with a voltage source whose waveform matched that of a loaded generator. Calibrated thermocouple voltmeters were used as standards.

Meters whose resistances were 5,000 ohms per volt or greater were required to measure B and C voltages in order not to load the power supply.

For measuring the speed of rotation of generators, tachometers were designed that were actuated by the frequency of the A voltage. In general, the tachometers consisted of an amplifier, wave clipper, and vacuum-tube voltmeter which read the average voltage across an RC net work. A number of circuits were developed for this purpose[8, 22] but the most satisfactory one, as well as the one used most extensively, is shown in Figure 18.

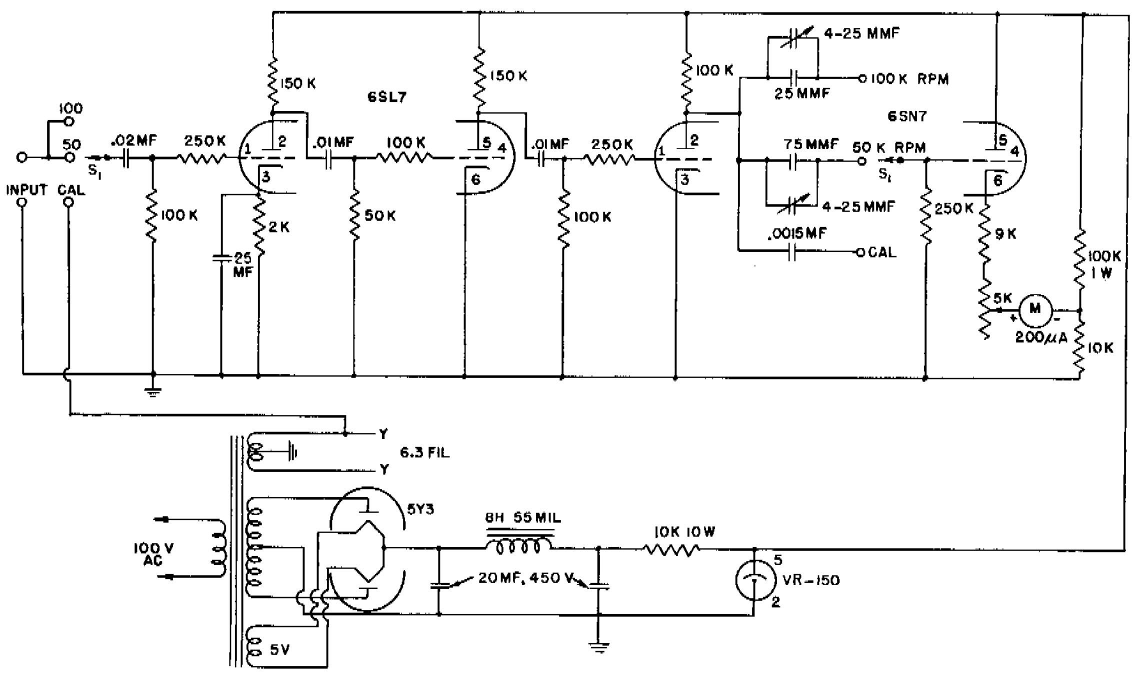


FIGURE 18. Circuit diagram of tachometer used for measurement of rotational speeds.

7.6 SPECIAL TESTS ON COMPLETED UNITS

7.6.1 Introduction

Although the observations in the final test position (referred to in Section 7.4 and described in detail in Section 7.8) provided the most important data on completed fuzes, other special or supplementary tests were required. The nature of these tests varied with the type

[redacted]

of fuze. Some were 100 per cent or production tests, that is, they were performed on all fuzes of a particular type. Others were sampling tests; that is, only representative samples from production lots were tested.

The most important of the special tests on completed fuzes are described in this section.

7.6.2 Pulse Test

The pulse test was given each fuze after final assembly in its encasing can to insure that it was operating electrically after all test leads had been disconnected and the encasing can staked. The pulse test occurred after the "final" test, since the latter was made with a number of special test leads soldered to the fuze. An r-f pulse of appreciable magnitude was impressed on the fuze by grounding a metal plate near the nose, or grounding the antenna itself. If all electric circuits were continuous and functioning, the thyratron would fire a simple neon firing indicator connected to the detonator contacts in place of a detonator. The pulse test thus provided a simple overall check of the assembled unit in its encasing can.

7.6.3 Tests of Self-Destruction Circuits

For those devices with self-destructive [SD] circuits (T-5), tests were performed to check the length of time required for this circuit to function. Both mechanical and electric SD devices were used. The SD time could be roughly measured with a stop watch. However, circuits were devised which recorded the time on an electric clock.

7.6.4 Arming Pulse

An arming pulse test was performed on T-5 fuzes to insure that transient pulses due to the application of voltage to thyratron plate and/or disturbances of the r-f field present at the arming switch did not fire the thyratron.[5] If the thyratron did not fire when armed, the fuze was satisfactory in this respect. The test was not considered necessary on later models (T-50, T-51, etc.), since extensive laboratory tests of these designs demonstrated the absence of arming pulses.

7.6.5 Warmup

A warmup test was performed as a sampling test on T-5 units to insure that initial circuit transients were below firing magnitude when arming occurred. The transients were primarily due to filament warmup and condenser charging.[5]

7.6.6 Apex Firing

An apex firing test was under development for mortar fuzes, but such a test was never actually performed in pilot production testing. The necessary investigations were made, however, for the test which was intended to insure that the thyratron would not fire at the apex of the trajectory where the supply voltages developed by the generator dropped to very low values. A number of factors occur at the apex of the trajectory which tend to fire the thyratron either as the generator slows down or speeds up.[26]

7.6.7 RC Arming Delay

The RC arming delay was measured on fuzes which used this type of arming as an additional safety feature. The test insured a certain minimum capacitance for the detonator-firing capacitor and an RC product within specified limits. Details of these requirements as they pertain to RC arming are given in Section 3.3.6.

7.6.8 Shelf Life

Shelf or storage tests were performed at periodic intervals on a group of T-5 fuzes by subjecting them to the usual performance tests.[31] The most serious effect of long storage was detuning (cf. Section 3.1).

7.7 SERVICE TESTS

7.7.1 Introduction

The service use of fuzes in wartime involved conditions of transportation, handling, storage, and installation which imposed severe requirements on design and construction. Ruggedness and resistance to extremes of atmospheric conditions were essential properties of the fuzes if they were to withstand rigors of wartime use. Some of the extreme conditions involved in transportation and storage were mollified by the container or package in which the fuze was shipped, but the fuze was still subject to considerable rough handling and atmospheric extremes after unpackaging. The bomb fuzes, for example, were required to be carried in bomb bays for extended periods at very low temperatures and then to operate properly when released.

The so-called service tests described in this section were designed to test the ability of fuzes to perform properly under operational conditions.

7.7.2 Jolt Test

Fuzes were subjected to a jolt test (on a sampling basis) to test mechanical strength and ruggedness of construction. The test was performed according to Ordnance Department specifications. The jolt machine used for the test consisted of a series of arms, operated by rotating cams, which held the fuzes (Figure 37, Chapter 4). As the cams rotated, the arms were raised in turn and allowed to drop on a wooden block. It was required that the fuzes pass critical operating tests after jolting.

7.7.3 Vibration and Packaging Tests

A vibration test was performed on fuzes to simulate conditions resulting from vibration of an airplane in flight. The test was adapted from the Navy Department Bureau of Ships specification for type testing of airborne electronic equipment. The test consisted of vibrating fuzes at frequencies of from 10 to 55 c at an 0.06-in. amplitude for 30 min. It was required that the fuzes pass critical operating tests after vibration.

Standard ordnance packaging tests were performed on fuzes in their container. The tests included shock, jumbling, and exposure to atmospheric extremes. The fuzes were tested for overall performance before and after the packaging test, and if the fuzes performed properly on retest, the packaging was considered satisfactory. The packaging tests, except for the electric measurements, were made at Picatinny Arsenal.

7.7.4 Temperature Tests

Two types of temperature tests were made on fuzes, one on the completed fuze and the other on the head and the power supply. The first, a temperature cycling test, was made on the completed fuze and simulated the alternate extremes of high and low temperature encountered in transportation and storage. The fuzes were subjected to a number of cycles of high and low temperatures, after which they were tested for mechanical and electric performance. After the test, it was required that a fuze meet certain electric and mechanical requirements which allowed limited changes from prior performance. The second test, which was performed on the fuze head and the power supply separately, was an operational test performed while the head, or power supply, was actually operating under a condition of extreme temperature. The temperatures used were -40 and $+60$ C. It was required that certain parameters of the head, or power supply, should not differ by more than certain small percentages from their values when measured at a temperature between 20 and 30 C. (See specifications listed in the bibliography of Chapter 5.)

7.7.5 Humidity Tests

Humidity tests were made in order to duplicate conditions to which fuzes would be subjected in tropical climates where during the day

there was high humidity and temperature, with lower temperatures and high humidity at night. Tests were made in a controlled humidity chamber where the temperature could be cycled, duplicating the breathing as occurs in service use. As with the temperature cycling tests, performance data after humidity cycling had to be within certain specified limits of the prior values. (See specifications listed in the bibliography of Chapter 5.)

7.7.6 Salt Spray Tests

Salt spray tests were made to determine the effect of the corrosive action of sea water and spray. Tests were made according to Army and Navy aeronautical specification AN-QQ-S-91, with the requirement that the fuzes operate satisfactorily both electrically and mechanically after treatment.

7.7.7 Centrifuge or Accelerating Tests

Centrifuging tests were performed to determine the effects of appreciable acceleration on the fuzes. Only those fuzes which would experience accelerations in service were so tested (rockets and mortars). The chief defects caused by centrifuging were failure of mechanical parts and displacement of circuit elements which created changes in electric performance. Both commercial and specially built centrifuges were used. The smaller fuzes could be accommodated in commercial centrifuges, but a special double-beam type of centrifuge was built for the larger fuzes[4] (see Figures 32 and 33, Chapter 4).

7.7.8 Field Test Set IE-28

A field test equipment known as the IE-28 test set was developed for field testing major subassemblies of T-5 fuzes. It is shown in Figure 19. It was designed primarily to test batteries before final assembly in the field but was also arranged to provide tests for the arming switch and the electronic assembly (MC-382). The test of the latter was a pulse test similar in purpose to the one described in Section 7.6.2. Tests on the switch checked the safety (i.e., unarmed condition) and continuity of the electric detonator.

Simple laboratory tests of this sort, made in the field just prior to use, were considered desirable for T-5 fuzes primarily because of the newness of the fuze as an ordnance item. No similar tests were considered necessary or desirable for generator-powered fuzes.

The IE-28 test set was made to test either T-5, T-6, or T-4 (photoelectric) fuzes. The fuze head (MC-380) shown in Figure 19 is part of the T-4 fuze.[b]

FIGURE 19. Field test set IE-28 with T-4 fuze in position for testing.

7.8 MECHANICAL TESTS AND GAUGING

7.8.1 Introduction

Mechanical tests were required to insure maximum safety of the fuzes and proper operation of the mechanical parts, particularly the high- and low-speed rotary systems. Gauging operations were performed on dimensions

[b] This fuze is described in Division 4, Volume 3, Summary Technical Report.

which were critical in determining interchangeability of parts or in determining fit or clearances in Service use.

7.8.2 Static Torque Tests

A static torque test was made on the windmill to determine the torque required to turn it from a stationary position. The gauge used incorporated a spring device which either indicated the torque directly on a scale or caused a light to glow if the measured torque was greater or lower than specified limits. The purpose of the lower torque limit was to insure the existence of sufficient magnetic lock (see Section 3.4.5). Windmills of fuzes meeting this requirement would not turn below a certain minimum air velocity (about 150 fps). The purpose of the upper torque limit was to insure that the rotary system was free to turn.

The static torque test was repeated with the fuze under compression[28] and at various temperatures between −40 and +60 C. This test was made to insure free turning of the rotary system when subjected to the force produced by tightening the booster cup and when operated under extreme conditions of temperature. The compression applied during the torque test was sufficient to give an indication of the compression strength of the fuze. The force was applied (for ring-type fuzes) between the interrupter plate and the antenna ring.

A torque test was performed on the detonator rotor to insure that the force required to move this rotor into its final position would not be too great on account of possible stiffness in the detonator contact springs. The test was performed with a torque gauge similar to that used for the static torque test for the windmills. It was found that adherence to the limits of this test was an important factor in preventing duds.

7.8.3 Binding and Dynamic Torque Tests

A mechanical binding test was performed on the completed fuze to insure that no tight spots existed in the rotating system due to tight or defective parts. If the speed of the fuze was within certain limits when driven by a low and constant pressure airstream, it was considered satisfactory. This same test was performed under temperatures ranging from −40 to +60 C to insure that mechanical binding would not occur at extreme operating temperatures.

A dynamic torque test was made on the larger type fuzes, i.e., bomb fuzes, where the propellers could be driven by a motor drive.[29] The purpose of the test was to insure that the dynamic torque required to drive the rotating system would be within limits which would not give undue variations in arming times. Too little or too great dynamic torque would cause higher or lower propeller speeds respectively, with corresponding variations in arming times. The torque was measured by means of a torsion wire, the torque reaction being measured by the amount of twist of the wire (Figure 20).

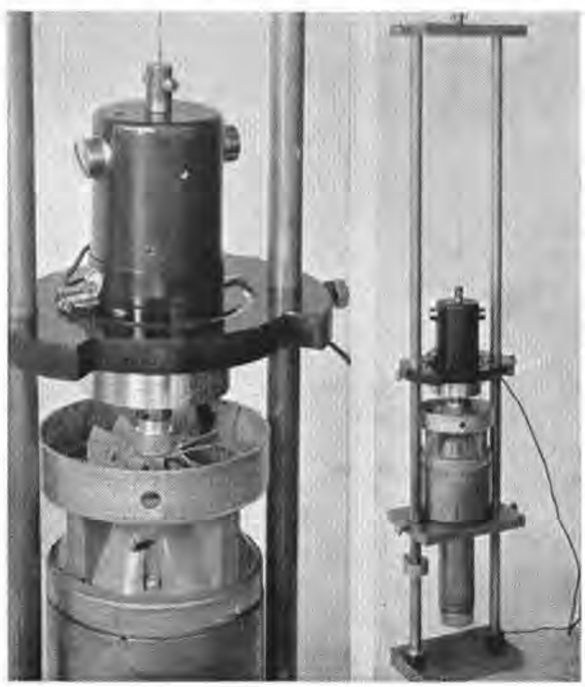


FIGURE 20. Torsion wire dynamometer used to measure dynamic torque.

The torques measured were of the order of 1.3 in.-oz at 8,000 rpm.

7.8.4 Other Mechanical Tests

Dipole strength tests were made on bar-type

[redacted]

fuzes by applying a force at a point $\frac{1}{4}$ in. from the outer end of the dipole and perpendicular to both the axis of the dipole and the axis of the fuze. The original test called for an 80-lb applied force, while 150-lb force was later specified for models which used stronger plastic materials in the nose. The requirement for the test was that the dipole should successfully withstand several applications of the force.

7.8.5 Gauging

Gauging was performed on dimensions which were critical in determining interchangeability of parts. Thread gaugings were probably the most important operations. In the complete fuze assembly three sets of threads were involved, namely, threads on the casting containing the electronic assembly which mated with threads in the encasing can (potato masher); outside threads on the encasing can for screwing the fuze assembly into the missile; and threads on the tetryl cup which mated with threads in the encasing can. These threads were gauged with appropriate thread gauges. Other types of dimensions gauged included diameters and depths of holes and overall lengths of parts and threads. Ordinary commercial snap, plug, sight, and concentricity gauges were used, as well as many special gauges developed particularly for the jobs at hand.

In addition to gauging the critical dimensions mentioned above, measurements were made of electric and mechanical arming angles and the height of the detonator contact springs. These three items were critical because improper adjustment of any one or all of them could cause improper operation of the arming system. Electric arming angles were measured with an automatic turns counter. Mechanical arming angles and contact spring height were measured with suitable gauges.

Vane blade angles of metal windmills were measured with a Bausch and Lomb comparator. These measurements were important in keeping the effective pitch of the windmill constant. Variation in pitch would, of course, cause variations in time to arming (see Section 9.2.2). Bakelite windmills were not subject to such variation since they were molded.

The spring tension of the transfer pin contained in the detonator rotor was measured to insure its proper function in springing out to release the rotor from the slow-speed shaft and then hold it in the armed position. Insufficient spring tension might permit the detonator rotor to ride beyond the armed position and cause a dud, while too much tension would drag the shaft with a possible failure of the gear train, again causing a dud or excessive drag on the generator. It was also necessary to check the alignment of the transfer pin with respect to the keyway of the slow-speed shaft and the arming hole wires; incorrect alignment might produce binding of the rotating system.

Mechanical life tests were not usually run except during experimental or pilot production. The procedure used in such cases was to subject fuzes to mechanical operation for a given length of time and then test them electrically to determine any changes from previous performance. This process was then continued indefinitely until mechanical or electric breakdown occurred or until it was apparent that the fuzes under test had more than satisfactory mechanical life.

7.9 PILOT PRODUCTION TEST LINE

7.9.1 Introduction

During the process of unit assembly it was desirable to make certain routine checks to insure the completion of high-quality fuzes and a low percentage of rejects. The proper testing of units during assembly prevented systematic difficulties (lots of poor components or improper assembly operation) and permitted repairs while components were accessible.

Test positions which combined the essential laboratory tests and techniques outlined above and yet would not appreciably slow down the assembly process were, therefore, designed to check assemblies at various times during production.

When designing test equipment for the model shops and pilot production lines the most diffi-

[redacted]

cult problem was incorporating the special features required by the various types of units so that new equipment would not be necessary for every fuze model. This requirement led to the development of universal test equipment. That is to say, equipment was developed in which rewiring of the test panels was not required every time a new fuze type was to be tested. The panel contained switches or plug-in assemblies which could easily be altered as the test specifications required.

In addition, when possible, the equipment was "unitized," that is, made of component assemblies which could be used interchangeably at different places and could be easily replaced in case of failures. For example, the universal test panel and cathode follower were used in five of the ten positions, and the tachometer in three positions.

Since this equipment was to be used continuously and had to yield data of considerable accuracy, prime design factors were simplicity, ease of operation, ruggedness, and precision. Simplicity and ease of operation could not be overstressed, because complexity confused operators (who were relatively unskilled) and made maintenance and calibration difficult. Innumerable test jigs were designed and used, since the various manufacturers had preferences in techniques. Some stressed simplicity, some ease of operation, some accuracy, etc., but essentially they held the item to be tested and were similar to those illustrated below.

Figure 21 shows a typical test line, which, it will be noted, follows the assembly procedure outline in Figure 1 of Chapter 6.

Subsequent Figures 22 to 39, inclusive, show pictorial diagrams and schematic circuits illustrating the test positions of Figure 21. The illustrations are for one type of fuze; however, modification of the fixtures and voltage dividers was all that was required for the other fuze types, except for OD and POD fuzes. For the latter the circuit was arranged to measure plate current instead of grid voltage. For the OD fuzes an extra switch position was required for reading diode voltage. (These models were not in production at the close of World War II; therefore, the remainder of this section will deal with the RGD type fuze. References 2, 5, 40, and 51 contain details for testing specific fuze types.)

The presentation in the remainder of this Section follows the block diagram of Figure 21.

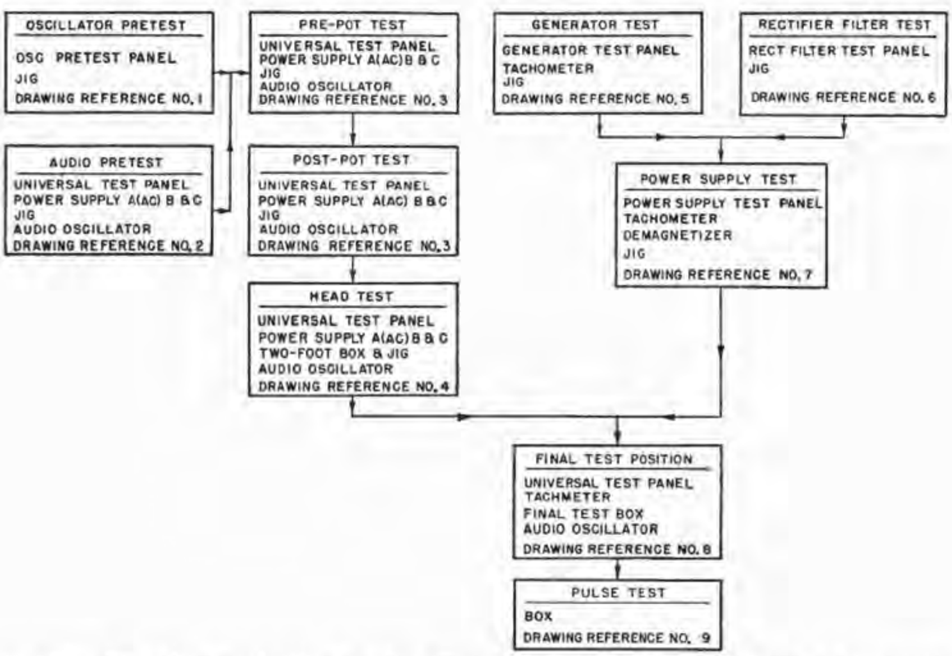


FIGURE 21. Pilot shop production test line. Drawing references are listed in the Bibliography.

7.9.2 Oscillator Pretest Position[c]

In the oscillator pretest position, the r-f assembly was complete except for the antenna ring, cap, or dipoles, since the antenna was not added until just prior to the head test position. The subassembly was mounted on jigs consisting of a shield can which contained a properly adjusted resistance and reactance load to compensate for the absence of the antenna. An electronic power supply replaced the generator for the operating voltages. It might be pointed out that any voltage equivalent to 1.4 volts rms was satisfactory for the filaments, so that for simplicity a filament transformer in the power line was used. A milliammeter in series with the B voltage measured the plate current, while a high-resistance voltmeter read the grid voltage developed by the oscillator. Any of the various types of wave meters (or receivers) could be used to measure the frequency, provided it was not too tightly coupled to the oscillator. In general, there was sufficient radiation from the test leads to operate the wave meter. Otherwise a probe was inserted into the shield can.

For pilot and model shops it was desirable to use directly calibrated meters and indicators, since the data acquired were used for correlation purposes. However, production line equipment was frequently marked so that the indicators showed only the tolerance limits.

7.9.3 Audio Pretest Position[d]

In the amplifier pretest position, the subassembly included the amplifier and thyratron circuits. Here measurements were made of the millivolts to fire, and when necessary, the frequency shaping and the normal critical voltage of the thyratron. The gain-adjusting gimmick was set at this test position (in designs which incorporated this feature). The millivolts to fire were measured at either the amplifier peak frequency or at fixed frequencies to determine the characteristics of the pass band.

Supply voltages were obtained from regulated electronic supplies which were set to deliver prescribed voltages (1.4 volts at 1,000 c, 140 volts direct current, 7.5 volts, and 2 volts direct current) to the amplifier under test. This

FIGURE 22. Oscillator pretest position.

position contained the necessary thyratron firing indicator, cathode follower, and output indicator, audio voltage source, and voltage

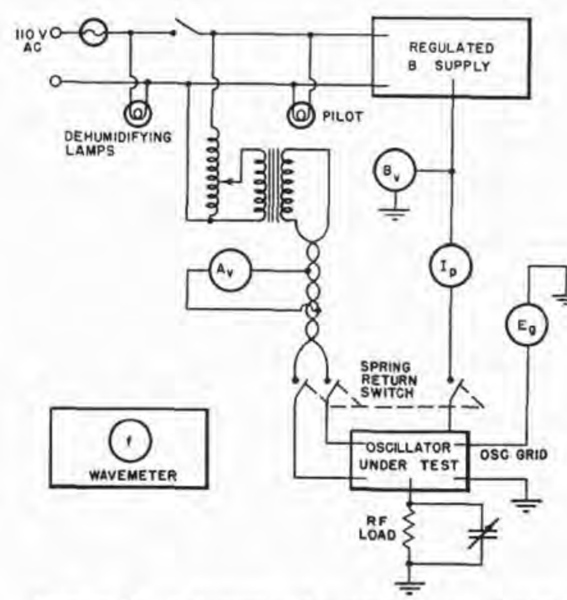


FIGURE 23. Schematic of oscillator pretest position.

divider. The voltage divider was in the form of a plug-in assembly which could easily be changed when testing other types of amplifiers.

[c] See Figures 22 and 23 and drawing reference 1.
[d] See Figures 24 and 25 and drawing reference 2.

This position consisted of the following unitized panels: (1) regulated power supply, (2) universal test, (3) audio oscillator, and (4) the necessary jigs.

For those fuzes which had the rectifier and filter circuits housed in the audio compartment (T-82, T-132, T-171, T-172), power supplies were provided to furnish a-c voltage to the rectifier-filter network. In the latter cases, it was possible to make a spot check of millivolts to fire with these components in operation.

FIGURE 24. Audio pretest position.

7.9.4 Audio Prepot and Postpot Test Positions[e]

After the oscillator and amplifier were connected together and assembled into the chassis (casting), quick checks of oscillator grid voltage, plate current, millivolts to fire, and normal critical voltage were made to insure no errors had been made in assembly. Then, after the assemblies were potted, they were again checked to eliminate those units whose characteristics had changed abnormally during the potting process. Certain small systematic changes were expected because of the change in stray capacitance caused by the added dielectric material.

These test positions were similar to the audio pretest except for the addition of a grid voltage meter and a jig which contained an r-f load similar to that used in the oscillator pretest position.

[e] See Figures 26 and 27 and drawing reference 3.

7.9.5 Head Test Position[f]

When a fuze assembly reached the head test position, it was completely assembled except for the power supply. The antenna cap, ring, or dipole (depending on the type of fuze) had been sealed in place. Here any final adjustments were made,[g] such as final setting of the gain control gimmick and determining the value of the padding resistor which normalized the B load of the headed unit. Normalizing of the B load was essential to keep the C bias within specified limits (see Section 3.4.5).

The test panel was identical to the audio postpot panel except for the jig.

The r-f jig consisted of a 2-ft shield box containing the necessary mount and lead connections. An r-f load (as described in Section 7.2.4) matching the free-space load was considered part of the r-f jig. Sensitivity and stability tests were made at this position as required.

7.9.6 Generator Test Position[h]

The generator was checked not only for the A and B voltages developed across specified loads, but also for alignment of rotor and pole pieces and the ability of the rotor to withstand high speeds. With the newer rotors, the latter becomes less important. Heavy mechanical shielding was necessary, however, to confine rotor fragments if one should fracture.

The A voltage was measured with conventional a-c voltmeters when the proper resistive loads were applied across the windings (see Section 7.5.8). The B voltage was rectified and filtered with a mockup vacuum-tube rectifier which was adjusted to duplicate characteristics of an average rectifier-filter section. In general,

[f] See Figure 28 and drawing reference 4.

[g] It should be mentioned that at this test position, the diode resonant circuit of OD units was tuned and locked.

[h] See Figures 29 and 30 and drawing reference 5.

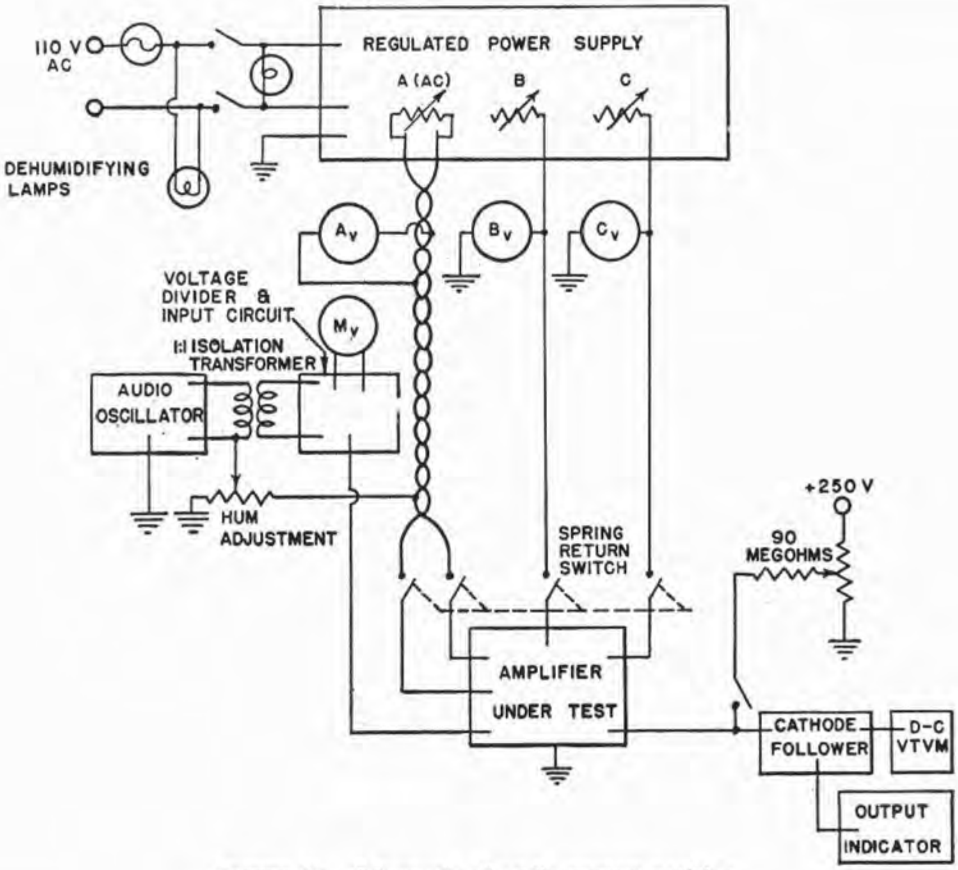


FIGURE 25. Schematic of audio pretest position.

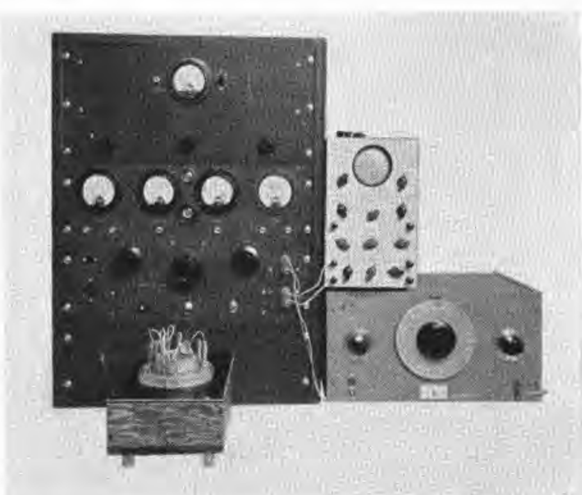


FIGURE 26. Audio prepot and postpot test position.

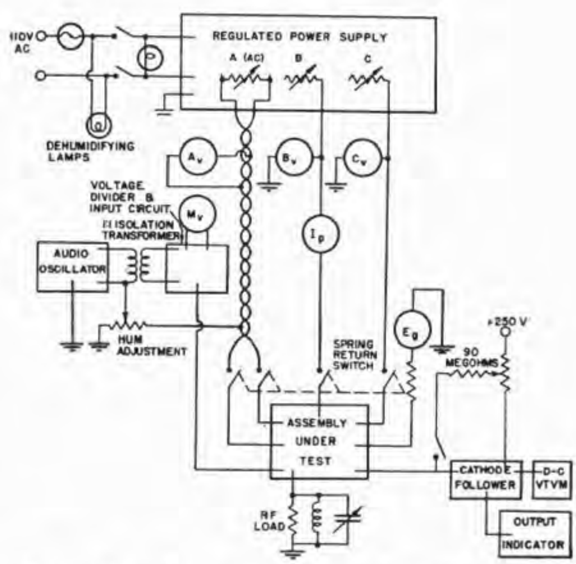


FIGURE 27. Schematic of audio prepot and postpot test position.

[redacted]

the voltages were measured at specified speeds, and occasionally regulation data was obtained at this test position. Regulation and B/A ratio tests were not performed as routine tests and usually required precision circuits (see Section 3.4.5).

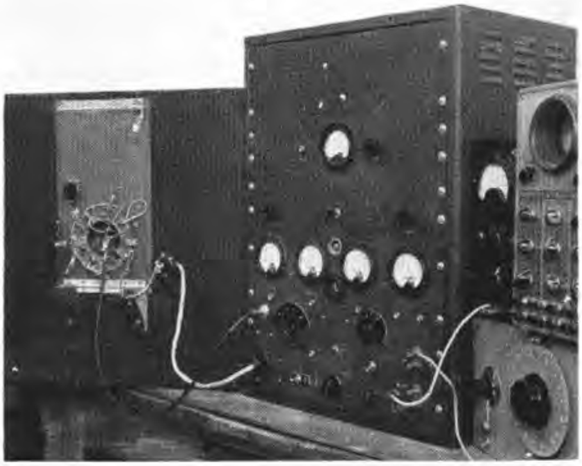


FIGURE 28. Head test position.

While at this position, the rotor was demagnetized until the proper voltages were obtained or until a slightly higher voltage was obtained. The latter procedure permitted further demagnetization at a later test position to compensate for differences in loads and rectifier-filter performance.

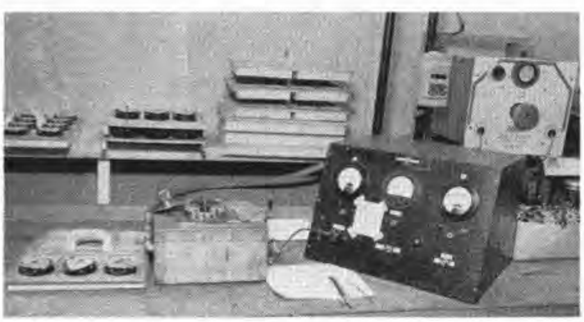


FIGURE 29. Generator test position (Bowen).

7.9.7 Rectifier-Filter Test Position[i]

The rectifier-filter section consisted of a resistor-condenser network which rectified and filtered the a-c B voltage. Taps were included for the required C-bias voltage or voltages. In addition, this assembly usually contained the contacts for the detonator rotor.

An a-c voltage was supplied to the rectifier-filter section from a generator whose output impedance was similar to that of the fuze generator. The a-c voltage required to produce a given d-c voltage across the output and the no-load source voltage were measured. These two values give an indication of the efficiency of the rectifier subassembly.

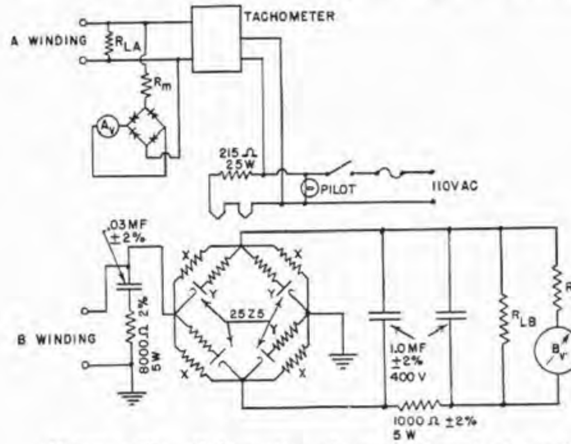


FIGURE 30. Schematic of generator test position. R_{LA} and R_{LB}—load resistors adjusted as specified. X and Y adjusted to match ideal rectifier assembly.

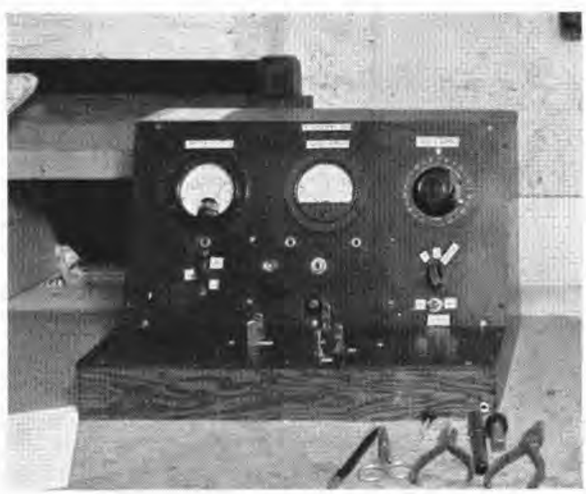


FIGURE 31. Rectifier filter test position (Bowen).

Metering circuits for measuring the C bias,

[i] See Figures 31 and 32 and drawing reference 6.

the a-c ripple across the B load, and the continuity of the detonator leads were included.

7.9.8 Power Supply Test Position[j]

After assembly of the generator and rectifier-filter, the completed power supply was tested

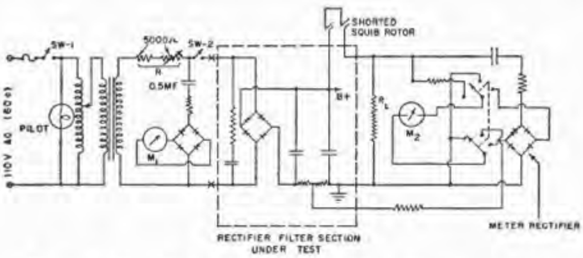


FIGURE 32. Schematic of rectifier filter test position. M_1 — 0-400 volts alternating current, M_2 — 0.200 volt direct current and 0-10 volt alternating current. Filter section to see a total load (R_L) of 8,000 ohms ± 2 per cent including meter resistance. Effective impedance of source looking back from points X-X shall be 7,700 ± 1 per cent including R and meter resistance. Reactive component shall be less than 1,000 ohms.

and the voltages adjusted for the proper fuze load. This final adjustment was accomplished either by demagnetizing the rotor or loading the B filter and adjusting the C-bias network.

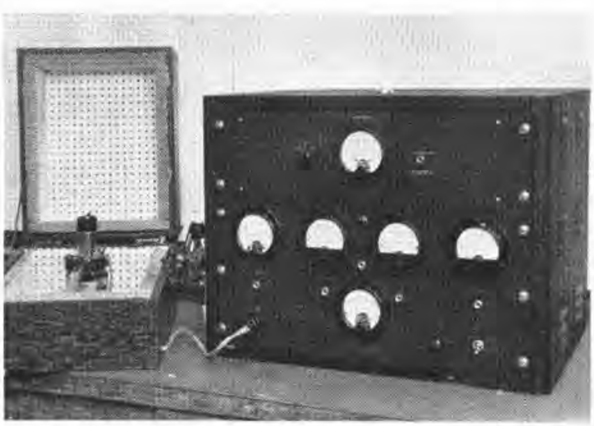


FIGURE 33. Power supply test position.

The test panel contained the necessary A, B, and C voltage meters, a tachometer, and demagnetizing equipment. The jig contained an air turbine driver, contact prods, and the A and B loads.

7.9.9 Final Test Position[k]

The performance of a fuze at final test was established as the basis for product acceptance.

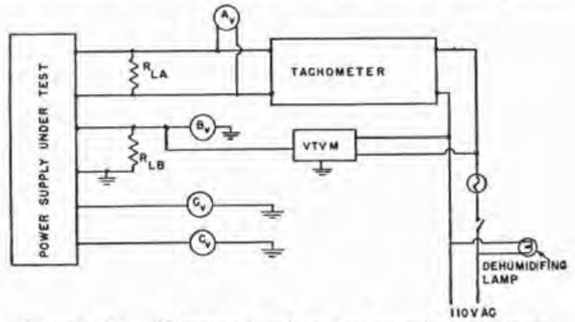


FIGURE 34. Schematic of power supply test position.

For this reason, this test position was most elaborate. Here the critical electric voltages were measured (A, B, and C, oscillator grid bias, millivolts to fire, and effective critical voltage) under conditions which simulated as near as possible free-flight conditions. The free-

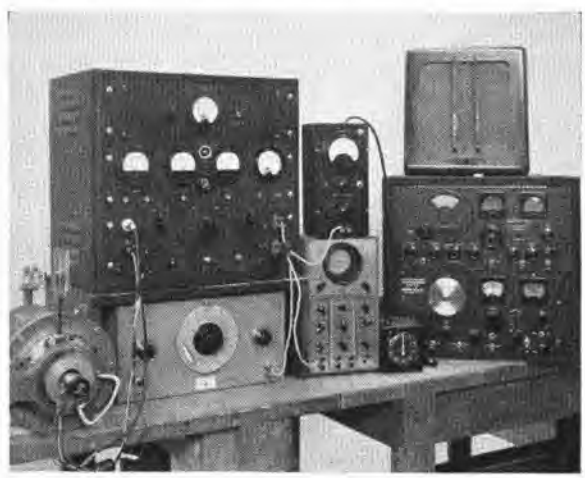


FIGURE 35. Final test position for ring-type fuzes.

space r-f load was duplicated in a shielded box or chamber, as described in detail in Section 7.2.4. The fuze was mounted on a mechanical

[j] See Figures 33 and 34 and drawing reference 7.

[k] See Figures 35, 36, 37, and 38 and drawing reference 8.

system which permitted vibration, while the circuits were operated by power supplied by the fuze generator. The generator was driven with a stream of high-velocity air directed through suitable jets at the vanes of the windmill.

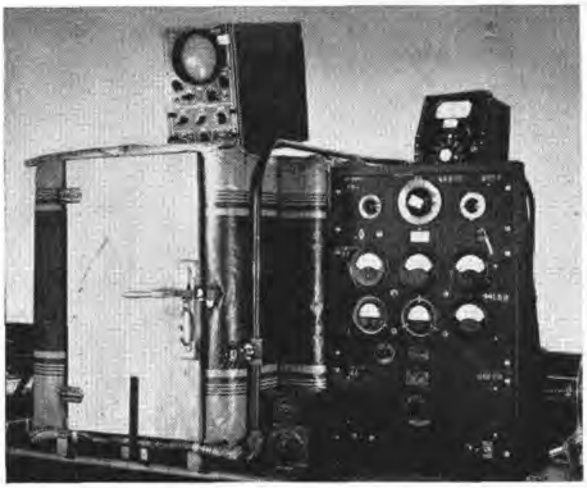


FIGURE 36. Final test position for bar-type fuzes (Zenith).

The most difficult problem connected with the final test position was the securing of adequate contact to the test points and obtaining the proper vibration as discussed in Section 7.4.1. With the standard size fuzes, test leads were soldered to the connecting lugs on the amplifier base plate, as no other system was devised which permitted good contact under the necessary conditions of vibration. (See fuze on table in Figure 6.) In designing the miniature fuzes, special terminal boards (side view, Figure 14B) were incorporated which made possible the use of small, quick-acting clamps on which were mounted all the necessary test prods.

The test panel consisted of a tachometer and universal panel with the voltage meters, audio input and output circuits, and effective critical voltage measuring equipment.

The fixture was a shielded box or metal chamber containing the r-f load, air jet, and a resonant vibration mount similar to those described in Section 7.4.2. and Figures 2 and 5.

High-velocity airstreams were the most practical method of driving the windmills or turbines. The air was obtained from a line (pressure at 80 to 100 psi) and directed at the vanes through jets made from dielectric materials. The first jets were made of glass (see Figure 39). Plastic jets soon replaced these since the mortality of glass jets was very high. In places where r-f loading was not important, metal jets were used (see Figure 51, Chapter 4). The jet assembly consisted of an air reservoir from which vents issued. These vents were directed almost normal to the vane surface with a slight incline toward the leading edge to direct the airflow beyond the propeller. Typical plastic jets are shown in Figures 5, 14B, and 15. Jets of this type consumed approximately 20 cu ft per min.

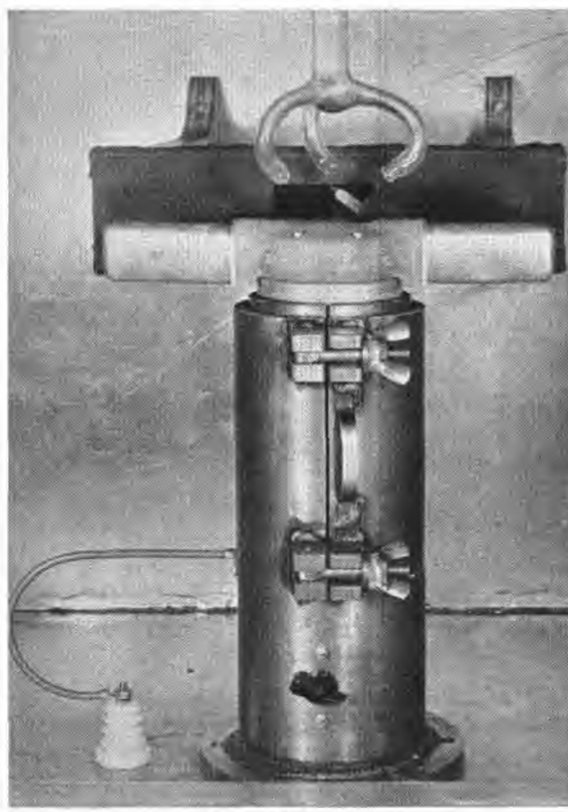


FIGURE 37. Inside view of final test position for bar-type fuzes (Zenith).

7.9.10 Pulse Test[1]

The pulse test was the last test made on a fuze before packaging. The fuze was at this point complete except for explosive elements.

[1] See Figure 39 and drawing reference 9.

All the test leads had been removed, and the encasing can staked in place. The purpose of the test was simply to insure that during these final operations no connections were broken or no leads short-circuited which would prevent the fuze from operating. Removing the test

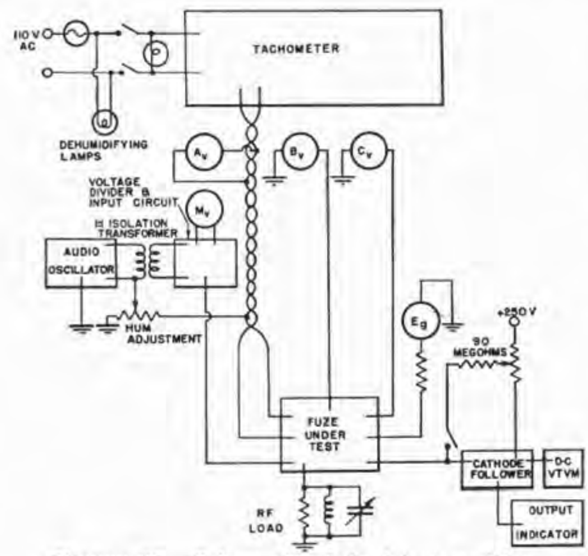


FIGURE 38. Schematic of final test position.

leads and staking the cans presented opportunity for accidents.

The complete fuze was mounted in a shielded box to eliminate extraneous noises and driven with an air blast. A neon lamp in series with a protective resistor and by-passed by a condenser and resistor were mounted on a detonator rotor in place of the detonator to serve as a firing indicator.

An r-f disturbance was produced to fire the thyratron by grounding an r-f pickup plate or by grounding the fuze antenna. The fuze was considered satisfactory if the neon fired only when the r-f field was disturbed.

7.10 QUALITY CONTROL TESTING

7.10.1 Object of Quality Control

Quality control laboratories were set up to check and control[54] the quality of all types of fuzes which reached the production stage. The accuracy of testing equipment at these laboratories was necessarily high. In addition, they served as a calibration center for checking equipment at the manufacturers. It was the express function of the quality control laboratory to indicate the trends of test data, note defects of manufacture and failure to meet specifications, and immediately to report the results to the manufacturer.

Quality control testing was under control of the Services; Division 4's participation in it was primarily of an advisory nature. Development of the test equipment used for quality control was, however, done largely in Division 4's central laboratories at the National Bureau of Standards. The intimate relationship between design of the equipment and the operat-

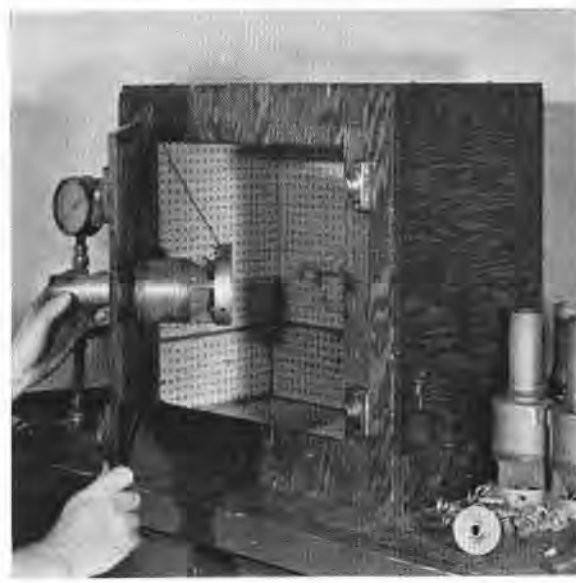


FIGURE 39. Pulse test position.

ing properties of the fuzes made development of test equipment an integral part of the fuze development program.

Test equipment used in the quality control laboratory was the same as used on similar tests on the production line. The production line, however, included tests on some parts and subassemblies which were not duplicated at quality control.

As mentioned in the introduction to this chapter, the sequence of operations at quality control was, in general, the reverse of those used on the production line. Quality control

began with a completed fuze and broke it down; the production line started with parts and subassemblies which were assembled into a completed fuze. Another difference was in the nature of the data taken. Actual values were recorded at quality control, whereas limit meters were usually used in production.

Eighteen typical fuzes from each lot of 1,000 were submitted to the quality control laboratory. Later, as quality improved, smaller numbers were submitted. These samples were selected at random from regular production by a representative of the contracting officer stationed at the factories. Tubes submitted to quality control were selected in a similar manner.

The routing of fuzes in the laboratory is shown in the following diagram (Figure 40) which is discussed briefly. The discussion will mentally or on fuze models which had not reached the production stage.

Quality control tests were of three general classes: (1) production, (2) sampling, and (3) type. The first were performed on all fuzes in the sample (the same tests were also presumably made previously by the manufacturer). Sampling tests were made on only two or three fuzes from each sample lot. These tests were more difficult to perform and impaired the quality of the fuze so that it was no longer suitable for field use. Type tests were usually of the same general nature as sampling tests, but were made only at irregular intervals. Particular occasions for making type tests were (1) on the qualification lot of a new design, (2) when a change in production procedure had been made which might conceivably change the properties of the fuzes, and (3) when

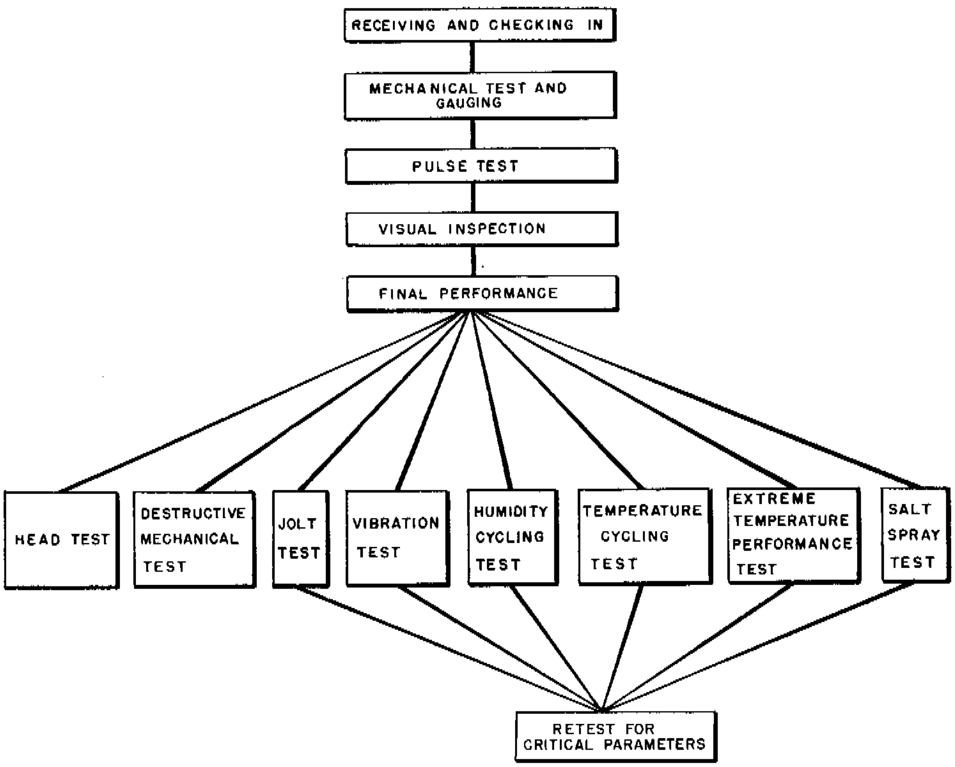


FIGURE 40. Flow diagram for quality control.

show only the position which each test occupied in the quality control program, since a detailed discussion of each has been included earlier in this chapter. Tests mentioned previously, but not included here, were used only experi- production tests had indicated an undesirable trend in the product.

In the following discussion the letters P, S, and T are used to indicate whether the tests were production, sampling, or type. ST indi-

cates type tests which were often run as sampling tests.

7.10.2 Mechanical Tests and Gauging

Upon being received and checked in, a lot of fuzes was routed to a laboratory where mechanical and gauging tests were performed. These tests included

1. Gauging of mechanical arming angle (P).
2. Measurement of propeller turns to electric arming (T).
3. Gauging height of detonator contact springs (S).
4. Gauging of detonator rotor housing (P).
5. Gauging of detonator rotor and transfer pin (P).
6. Measurement of tension of spring in transfer pin; alignment of transfer pin (P).
7. Gauging of tetryl cup and tetryl plate (P).
8. Static torque test (P).
9. Detonator rotor torque test (S).

Tests on gear trains were run on a sampling basis on the product used by the fuze manufacturer. Gear trains from finished fuzes were not tested separately.

Following mechanical tests and gauging, a visual inspection (P) was made for the purpose of noting possible mechanical defects, poor workmanship, or extraneous materials.

7.10.3 Overall Electric Tests

While the fuze was in the mechanical laboratory, in its encasing cans, it was given the pulse test (P). (See Section 7.6.2.) The encasing cans were then removed from all fuzes in the lot and the lot sent to the electric laboratory where the test leads were soldered in place. There the fuze was given the following electric tests and the mechanical binding test (final test position, Section 7.9.9).

1. A, B, and C voltage (P).
2. Diode voltage for OD fuzes (P).
3. Oscillator grid bias voltage (P).
4. Oscillator plate current for POD fuzes (P).
5. Carrier frequency (P).
6. Peak audio frequency (P).
7. Millivolts to fire at one or more frequencies (P).
8. Effective critical voltage and/or noise margin test (P).
9. Normal critical voltage (P).
10. Thyratron grid circuit voltage drop (P).
11. Mechanical binding test (P).

In connection with certain of the final performance tests, it should be pointed out that data for curves of millivolts to fire versus audio frequency, curves of effective critical voltage and C volts versus generator speed, and curves of A and B voltage versus generator speed may be made at the final test position. The millivolts-to-fire curves indicate the frequency characteristic of the amplifier, the intersection of the effective critical and C voltage curves show the lowest speed at which the generator can operate without premature firing of the thyratron, and the A and B voltage curves indicate the regulation characteristic of the generator. Such data were usually taken on a sampling or type basis.

7.10.4 Head Tests

Following the final performance test, part of the lot was given the head test which consisted of the following.

1. Tuning for OD fuzes (S).
2. Oscillator stability test (ST).
3. R-f sensitivity test (ST).
4. Oscillator plate current test (ST).

All head tests on a group of units were usually performed by one operator, though not necessarily at one test position. An external voltage supply was used to furnish power (usually alternating current for the filaments and direct current for the plate supply).

7.10.5 Special Tests

After the head test, various fuzes of the lot were routed to the remaining tests included on the diagram, namely,

1. Destructive mechanical tests.
   a. Dynamic balancing tests (ST).
   b. Strength tests (S).
   c. Vane pitch measurements (S).
2. Jolt test (ST).
3. Vibration test (ST).

[redacted]

4. Humidity cycling test (ST).
5. Temperature cycling test (ST).
6. Extreme temperature performance tests (ST).
7. Salt spray tests (ST).

The strength tests included dipole strength tests (T), for bar-type fuzes, and compression tests (ST) on the complete fuze assembly.

7.10.6 Tube Tests

Tubes were supplied to the fuze manufacturers by the Army. In order to maintain the quality of the tubes as furnished, the Army also required that quality control tests be run on tube production. The tests performed were essentially those outlined in Section 7.5.2.

7.10.7 Limits and Tolerances

The limits and tolerances of performance required in quality control were somewhat arbitrary. In general, a compromise was made between ideal performance and allowances necessary to maintain production. Figures 8, 9, 18, and 19 in Chapter 6 indicate for some parameters the degree of uniformity that was obtainable. The limits imposed for the various fuzes are given in the specifications listed in the bibliography of Chapter 5.

[redacted]

Chapter 8

FIELD TESTING OF PROXIMITY FUZES[a]

8.1 GENERAL INTRODUCTION

THROUGHOUT THE DEVELOPMENT of radio proximity fuzes for nonrotating projectiles, field tests were relied upon to provide information under conditions which, because of ignorance of what such conditions were or because of the difficulties involved, could not be duplicated in the laboratory. It was demonstrated repeatedly that there was no laboratory substitute for field testing. From the first field tests in the early part of 1941, in which the characteristics of the reflected signal were investigated, to the service acceptance tests, field tests gave vital data on conditions under which the fuzes must operate, the effects of electrical and mechanical changes in design, and the quality of the final service fuzes.

Experience gained in the field testing of proximity fuzes also provided the basis for the necessary special instructions for handling the fuzes in service use. Although the special precautions for handling the fuzes (due primarily to the fact that missiles became radio antennas) were simple and easy to perform, they were essential for the best performance of the fuzes.

For the performance of these tests, proper proving ground facilities for releasing bombs from planes and for firing rockets and mortar shells had to be provided, and technical methods, mainly electronic, photographic, and pyrotechnic, had to be devised or adapted to provide the desired information. At first, when the volume of field tests was small, the facilities of established proving grounds were used, but later, as the volume increased, most of the testing of proximity fuzes was done in new proving grounds or ranges set up or reserved for the sole purpose of testing proximity fuzes. However, special tests continued to be performed in other locations, particularly tests on effect fields and demonstrations performed at the request of, or in cooperation with, particular branches of the Armed Forces.

The first field tests in connection with the development of bomb fuzes were performed in the early part of 1941 at Camp Springs, Maryland, the Naval Air Station, Lakehurst, New Jersey and the Naval Proving Ground, Dahlgren, Virginia. The greatest part of subsequent bomb fuze testing was performed at the Aberdeen Proving Ground, although important tests were also performed at Dahlgren, Virginia, Eglin Field, Florida, and Edgewood Arsenal, Maryland. At Aberdeen alone some 14,000 bombs were dropped in the field testing of bomb fuzes.

In February of 1942, rocket fuze tests were started at the Aberdeen Proving Ground. The need for additional facilities was soon evident, and a new proving ground was established at Fort Fisher, North Carolina, where test firing started in May 1942. Special tests, particularly those in which high-explosive [HE] loaded rockets were used, continued to be made at the Aberdeen Proving Ground. In the early part of 1943, a second proving ground, devoted to tests of proximity fuzes alone, was established at Blossom Point on the Potomac River, about 40 miles south of Washington, D. C. At first, because of the presence of a commercial air lane over this proving ground, firing was restricted to low elevations, but later in the year, after the air lane had been shifted to the west, permission to fire at any elevation was obtained. In December 1943, the proving ground at Fort Fisher, where approximately 11,000 rounds had been fired, was abandoned. At the Blossom Point Proving Ground nearly 14,000 rocket and mortar rounds were fired up to September 1, 1945.

The firing of mortar shells in connection with the development of the mortar shell proximity fuzes was started at Blossom Point in April 1944 and at the Clinton Field Station near Clinton, Iowa, in May 1945. Up until Septem-

[a] This chapter was prepared by Theodore B. Godfrey of the Ordnance Development Division of the National Bureau of Standards. David C. Friedman of the same organization assisted in the preparation of parts of Section 8.2. Section 8.4, including photographs and diagrams, was taken almost in its entirety from Chapter 7 of the Final Report of the University of Iowa.[42]

ber 1, 1945, approximately 1,950 mortar rounds were fired at Blossom Point and approximately 1,700 rounds at Clinton.

Since the methods used in the developmental field testing of bomb, rocket, and mortar shell fuzes were often the same or very similar, some repetition has resulted in order to make Sections 8.2, 8.3, and 8.4 each reasonably complete. When more details than are given in one particular section on some particular method are desired, they will often be found in one of the other sections. Details of proving ground technique are treated most fully in Section 8.4 on mortars; the described methods of testing are more numerous in Section 8.3 on rockets but there is less detail.

The test procedures described are, in general, those employed in tests performed under direct supervision of Division 4 (at Blossom Point, Aberdeen, and Clinton, particularly). Safety precautions, except as they were peculiar to proximity fuzes, are not discussed. The Safety and Security Division of the Ordnance Department, through periodic inspections, made recommendations which were very helpful in reducing the hazards connected with field test operations. Precautions for proper installation of the fuzes to secure best performance are discussed. These precautions were incorporated in Service manuals issued by the Ordnance Department for use with the fuzes.

8.2 BOMB TESTS

8.2.1 Introduction

Field tests of bomb proximity fuzes generally involved mounting the fuzes on standard bombs and dropping the fuzed bombs from standard bombers over the area in which observations were made. Both inert and HE-loaded bombs were used.

The great majority of bomb fuze tests under the direct supervision of Division 4 were performed at the Aberdeen Proving Ground. Figure 1 as a graphical representation of the accumulative total number of bombs dropped at Aberdeen.

Experiments with inert bombs were made to obtain information on the following points.

1. Fuze reliability.
2. Height of function.
3. Fuze generator characteristics (speed, speed regulation, bearing performance).
4. Arming distance.

Experiments with HE-loaded bombs were made to obtain information on the following

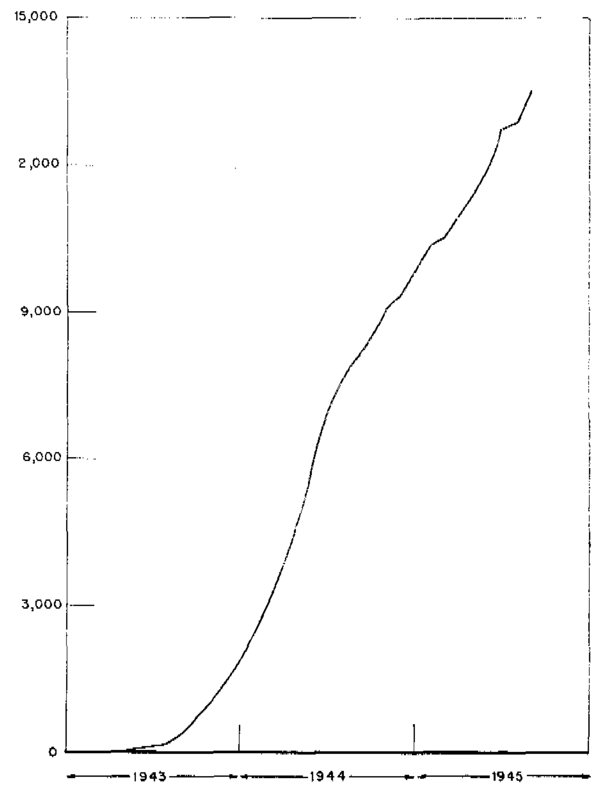


FIGURE 1. Accumulative number of bombs dropped at Aberdeen.

points in addition to those listed for inert bombs.

1. Minimum separation in train required to eliminate mutual interference.
2. Fragmentation pattern.
3. Optimum height of burst.
4. Effectiveness of air burst in comparison with ground burst.

8.2.2 Bombs Used

Standard bombs were generally employed in field tests and included those listed in Table 1. The weights given are nominal.

[redacted]

In addition to these standard bombs, other vehicles used have included the T-15 and T-16 fragmentation bombs, various fighter fuel tanks modified to carry napalm, and the British 4,000-lb blast bomb.

TABLE 1. Bomb types.

Type	Designation	Weight (lb)
General purpose	M-30	100
	M-57	250
	M-64	500
	M-65	1,000
	M-66	2,000
Semi-armor-piercing	M-58	500
Light case	M-56	4,000
Fragmentation	M-88	220
	M-81	260
Incendiary	M-76	500
Chemical	M-47	100
	M-70	115
	M-78	500
	M-79	1,000

8.2.3 Preparation of Bombs

The location of the bomb at the time of functioning of the fuze was obtained by photographic methods. Therefore, the preparation of HE-loaded bombs for tests of proximity fuzes presented no special problems, since the high explosive provides its own photographic flash. Other than the observance of standard precautions in the handling of HE-loaded bombs, care had only to be taken to insure that the fuze and tail were tightly mounted, since excessive mechanical vibration or intermittent electric contacts might cause random function of the fuze. Secure mounting of the fuze and fin to the bomb was recommended as standard procedure in the Service use of the fuzes.

The use of inert bombs, however, is to be preferred in developmental testing. The handling of bombs and the taking of data can be done much more conveniently without the hindrance of precautions which must be observed when high explosives are used. Therefore, a spotting charge arrangement to indicate the location of fuze functioning was devised for use with inert (mainly sand-loaded) bombs.

Spotting Charge. For the composition of the spotting charge itself, a mixture of 76 per cent 200-mesh potassium permanganate and 24 per cent 200-mesh magnesium (proportions by weight) was found to be very satisfactory. This mixture was loaded into cardboard cartridges, 5 in. long and 1 in. in diameter. (The preparation of such spotting charges is extremely hazardous and should be performed only by professional fabricators of pyrotechnical devices.) The spotting charge was taped to the rear end of the fuze, one end of the cartridge being in contact with the tetryl-filled booster cup.

It was found that the explosion of the booster and spotting charge was not capable of ejecting the fuze from the nose of a sand-filled bomb. Therefore, a steel pipe, 2 in. in inside diameter, was used to conduct the flame from the spotting charge to the tail of the bomb. An empty bomb case was used; the bottom of the fuze seat liner was knocked out and the tail plate removed. A piece of steel tubing, cut to the proper length, was inserted into the bomb case from the tail end and its forward end slipped into place over the fuze seat liner. The tail end of the tubing was plugged and centered by means of a special funnel through which the bomb was filled with sand. The funnel and tube plug were removed and the tail plate installed. The tail end of the tube was then centered and held in place by a tail fuze adapter from which the bottom had been cut out or by a special plastic plug.

It was found that fragmentation bombs, which have a low HE to total weight ratio, could be used satisfactorily for proximity fuze tests without sand loading and, therefore, without the installation of the steel tubing. The only preparation required consisted of knocking out the bottom of the fuze seat liner and removing the tail plug.

With this arrangement the interval of time between explosion of the detonator and the appearance of flash at the tail of the bomb is of the order of 4 msec.[12, 15] After the appearance of the flame a dense green smoke, easily visible to the eye, is formed.

8.2.4 Assembly of Fuze Components

Fuzes were received for field test minus all

explosive components. The detonator rotors were loaded at the National Bureau of Standards with the use of M-36 detonators (temporary developmental designations, T-3-E1, BS-5). The rotors were checked on a special test box for detonator continuity and transfer pin operation; only a small fraction of the minimum firing current was used in the detonator test. The rotors were inspected for projecting detonator contacts and any other roughness which might hinder operation.

The final assembly was done at Aberdeen Proving Ground. First, the rotor was inserted, the relative positions of the keyways in the shaft and rotor housing furnishing a rough check on the setting for minimum safe air travel. Next, the tetryl-filled plate was dropped in and engaged on the projection which held it in proper alignment. Then the tetryl booster cup was screwed in hand-tight. If the fuze were to be used on an inert bomb, the spotting charge in a cylindrical cardboard tube (1 x 5 in.) was secured to the cup with a short piece of 2-in. Scotch Tape.

8.2.5 Assembly of Fuze to Bomb

The fuze and puff combination was assembled to the bomb, either in the bomb bay or before loading of the bomb into the bay. The fuze was screwed in hand-tight when the spring-type washer was used and hand-tight plus ½ turn with a wrench when the lock washer was used.

The arming arrangement was examined to make sure that the arming wires would pull out properly, that there were no kinks where the wires might break under the load, and that the arming pins would function properly (cf. Figure 20, Chapter 4).

A wrench was used to tighten the fin locking nut, special care being exercised to eliminate rattle and possible consequent early functioning of the fuze.

Delayed arming devices, when used, were checked for release and for free spin before attaching, and for engagement and setting after the bomb and fuze had been mounted in the bomb bay.

8.2.6 Range Layout

Although some testing was done over ground with cloth targets for aiming points, and some over water with rafts as aiming points, so many disadvantages became apparent that a permanent water-target range was laid out at Aberdeen. The diagram used in locating impact points on this range is shown in Figure 2. The land-water boundary, not shown, lay close to the observers' stations.

The two permanent targets were built on piles. The horizontal surfaces (painted white) were planked with 2x10's on 20-in. centers and were about 10 ft above the water. Pile clusters were driven about 15 ft from each corner to protect the targets from drifting ice. A 25-ft pole was erected on each target to aid in estimating function heights.

The inner target, 1,980 ft from shore, was 30 ft square and was used for tests with inert bombs. The outer target, 2,215 ft beyond the other, was 20 ft square and was used for tests with HE-loaded bombs. No fragments from proper functions were ever observed to fall closer than the inner target. Fragments from random functions, however, fell 3,000 or 4,000 ft horizontally from the point of burst. Therefore, the bombing course was laid over a cleared area.

8.2.7 Communications

Plane-to-ground communication was accomplished with conventional Signal Corps receiving and transmitting equipment. The bombardier gave a 5-sec warning of "ready" and "fire" at moment of release. This was audible at each station through a wired intercommunication system. In addition, each station was provided with a portable radio receiver, which could be used to hear signals directly from the bombing plane.

8.2.8 Testing Conditions

Routine tests of fuze quality required the determination of function score, function

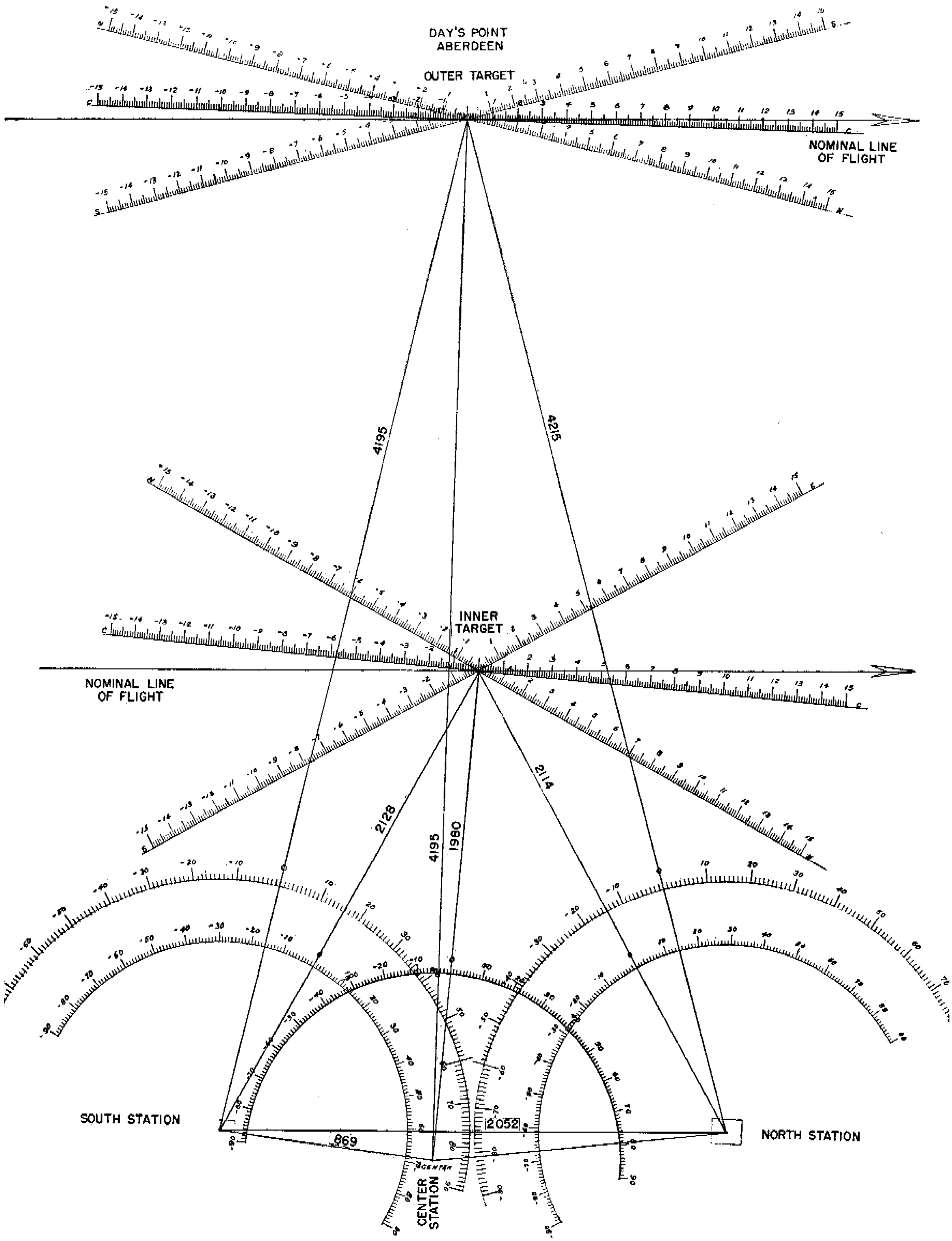


FIGURE 2. Bombing range at Day's Point, Aberdeen, with plotting board scales.

[redacted]

height, and fuze operation in flight. Factors influencing function score and function height include fuze sensitivity, vertical component of bomb velocity, angle of approach to target, and reflection coefficient of the target. To reduce the number of parameters, bombing was usually done at a standard speed (200 mph) and from a standard altitude (10,000 ft) over a large body of water with an essentially constant reflection coefficient. From laboratory tests and results of field tests under these conditions, the performance under other conditions could be computed.

Some tests were carried out under other conditions of plane speed and altitude to simulate, as far as fuze operation was concerned, the conditions of dive bombing. It proved very difficult to reproduce release conditions in dive bombing. Accordingly a system of release conditions was worked out for horizontal bombing in which the striking angles and approach velocities of the bomb were the same as for various conditions of dive bombing.[27] Still other tests were made from higher speeds and at higher altitudes to test the units under more severe conditions, or to test attachments for the fuzes.

8.2.9 Determination of Function Heights; Visual Methods

Function heights were estimated visually by a trained observer to make possible early discussion of test results and to supplement the photographic data, if incomplete. The observer was aided by the 25-ft pole mounted on the target and checked his estimates regularly with the photographic heights. The differences between visual estimates and photographic heights, obtained by trained observers, were remarkably small.

In addition, a camera obscura was often used as a visual means of obtaining function heights. Battery commander telescopes at the north and south stations and triangulation were used to obtain the range, so that the apparent height could be converted to actual height.

For engineering purposes, however, data obtained by photographic methods were usually required because of their greater accuracy.

8.2.10 Determination of Function Heights; Photographic Methods

Data for photographic determination of function heights were obtained by means of 16-mm motion-picture cameras, placed at the north and south stations (see Figure 2). Kodachrome film was exposed at the nominal rate of 64 frames per sec and was slightly overexposed in order to give the correct density for use on Recordak Viewers. Usually, a 2-in. focal length lens was used, but 15-mm, 1-in., and 3¾-in. lenses were also available. The 1-in. lens was used for photographing trains of bombs or in other tests where a larger field of view was required.

Normally, the camera was aimed at the target, and pictures of function, target and impact were obtained without moving the camera. However, on some drops it was necessary to swing the camera to obtain the picture of the impact. In such cases the photographer would note the azimuth of the splash with respect to the target. This was obtained from a scale mounted on the tripod head of the camera support. Often functions of wild drops could be photographed because the noise of the bomb could be heard, or the bomb seen, soon enough to swing the camera toward the point of function.

Each photographer was provided with a stopwatch, which he started when the bomb release signal was heard over the intercommunication system. Knowing the time of flight, he could start the camera a few seconds before impact.

In order to identify each round the photographer took pictures of a data board, on which were marked the station, the date, the photographer's name, the lens used, and the round number.

In order to provide an easy means of setting the scale on the Recordak Viewers, the photographer would take a picture at the beginning or end of the day's work of a scale pole from a distance of 500 ft, using the same lens as that

used for the day's program. The scale pole was painted alternately black and white in foot-wide strips. In addition, the first and last feet were marked with horizontal boards, which projected out from the pole. These bars showed up, even when the lighting or exposure was so poor that the black and white strips did not show with sufficient clarity.

When the film was received in the computing room, it was enlarged to a convenient size on a Model 10 Recordak Viewer. The picture of the target pole was used to set the scale, which usually was 1 ft on the pole equal to 2 mm on the screen.

The target was usually near the center of the film and was considered to be exactly there for purposes of computation. The error involved by the assumption was usually small. The horizontal distance from function to target and the vertical distance from function to splash were measured. If flash and splash were not in the same frame, the water-land boundary or the horizon were used as reference points. If the camera had been swung, the irregularities in the skyline were used as reference points in going from frame to frame, or the cameraman's notes were used to find the azimuth of the function.

Work was then transferred to a plotting board (Figure 2), consisting of a scale drawing of the range (1 mm equal to 10 ft) with scales running through the target perpendicular to the line between the camera and the target (one scale for each camera position). Additional millimeter scales were pivoted at the camera station points for locating the function. The horizontal distance measured on the Recordak, corrected for change in scale, was then transferred to the scale on the board, and the pivoted scale was passed through the projection on the horizontal plane of the apparent point of function. The same would be done for another camera station. Where the two scales crossed would be the projection of the function on the horizontal plane. The distances from the two cameras would then be read off directly from the pivoted scales. The measured vertical distances to the point of function on the film were then converted to the true vertical distances at the proving ground. This gave two values for the function height. In order for the determination to be acceptable, agreement between these two figures within 5 ft was required. The average was reported as the function height.

If the camera had been swung so that taking the projected distance would lead to too great an error, or when this distance could not be obtained because of blurring, the pivoted scale was passed through the azimuth obtained, as described in previous paragraphs.

It is estimated that the position of the flash may be determined by the method just described within 5 ft of its true position. However, the position of the flash of the spotting charge may not give the true height of function. A later section discusses possible error due to time lag of the spotting charge (see Section 8.2.13).

When very accurate function heights were required, a three-dimensional analysis of the film data was made.[9] Two projectors were set up to represent the cameras used in taking the film. The lenses were in the same ratio as those used to take the pictures. The range was laid out to scale, and a screen with the target location marked on it was set up at the scale distance to the target. The two projectors were then started and the pictures run, until the first sign of the spotting charge appeared. The film was then stopped and the cameras pivoted about an axis through the optical center of the lens until the images of the target coincided with the target location on the screen. The screen was then moved forward or backward, until the images of the spotting charge burst coincided. This located the burst in space. The apparent height of the burst was then measured and the scale of the setup used to convert this to actual function height. The accuracy of this method depends upon the scale used, the exactness of the match in lens ratio, and the ability of the operator to superpose the images. This method may be used to locate in space any portion of the trajectory made visible by smoke tracer or other means.

8.2.11 Determination of Function Time

Function times were determined in several

[redacted]

ways, depending upon the accuracy required. The usual means was visual determination by observers with stopwatches. The release signals used also depended upon the accuracy desired. The least accurate was a voice signal given by the bombardier over the plane-to-ground radio. The bombardier gave a 5-sec warning, then the release signal, when he dropped the bombs. This signal could be heard at the various stations by means of the intercommunication system. There were two types of automatic signals: a photoflash bulb on the plane fired when the bomb release was operated; and/or a squegging oscillator either started or stopped at release which could be heard via radio and the intercommunication system on the ground.

Function time was also determined from recordings on film or phonographic disks, of the output of a radio receiver tuned to receive the r-f carrier of the transmitter in the fuze. The starting signal, except when the squegging oscillator was used, was a standard 1,000-c note started as a warning by the chief observer and stopped by him when he saw the photoflash. When the bombs were dropped in train, this observer also recorded the times of random functions by momentary pulses of the 1,000-c note at each observed function. The fuze carrier was picked up by the receiver and its modulation detected, passed through a limiter[28] and recorded. The end of the modulation, except in rare cases, was an indication of the function or of the impact. By matching the 1,000-c note to a standard in the computing room, it was possible to run the record at the same speed as it was in the field and to obtain several determinations by stopwatch of the function time. By running the record at half or one-third speed, the error in time could be decreased. When film records were used, the film was driven by a synchronous motor, and a neon light recorded a time scale along the edge of the record of carrier modulation. When the line frequency was known, the time from the end of the 1,000-c note to the end of the carrier could be determined. When the line frequency varied too much, a 50-c oscillator[31] was used to operate the neon light.

Flight time was occasionally obtained by photographing a clock and the function on the same picture, using a high-speed camera. The clock was started at the release signal.

In most of these methods an error arises because of the use of one observer's reaction time to start but not to end the recorded interval. It has been estimated that the average error in observing function times was about 0.2 sec.

8.2.12 Observations of Fuze Carrier Characteristics

Investigation of fuze operation in flight was accomplished by picking up the fuze carrier and recording the modulation on film or phonograph disks, or both. Depending upon the frequency of the unit, a Hallicrafter S-27 or S-37, equipped with a long wire antenna, was used to receive the carrier. The audio output was passed through a limiter stage[28] to a Presto K-8 phonographic recorder or to a Dumont 3-in. oscillograph with a 16-mm camera attachment[29] or both. Speakers were also connected to the receiver output, one for the operator and one for the chief observer. The starting signal, which also provided the time scale signal, consisted of a 1,000-c note, which was started as a warning signal and stopped as a release signal by the chief observer. Round identification and pertinent remarks were placed on the record by means of a microphone connected directly to the recorder amplifier. The radio operator kept a list of film run numbers versus round numbers for identification of film traces.

The strength of the fuze carrier, which gives an idea of the overall performance of oscillator and power supply, was read from an S meter on the receiver.

The modulation may be divided into three types: noise, microphonics, and ripples associated with generator operation. The presence of noise usually indicated some mechanical trouble, such as binding or chattering gear trains or bearings, grinding off of parts of gear teeth, loose assembly of parts of the fuze or of the bomb, or bits of metal in the generator. Some of the troubles could be identified by comparison with records made in the laboratory.

Microphonics were caused by vibration of the elements of the oscillator tube and indicated

need for better mounting of the tube or better support of the tube elements.

Generator ripples gave data on the performance of the vane or turbogenerator system. A sudden change or an irregular variation in ripple frequency usually indicated bearing trouble. Some types of harmonic content indicated rectifier failure.

Considerable reliable data on generator speeds could be obtained from records of modulation of the fuze carrier. However, when accurate information on the speed characteristics of new driving systems was desired, it was customary to build special units each consisting only of an oscillator, generator, and driving system all in the regular fuze housing. In these units the plate supply of the oscillator was obtained directly from the generator, thus providing strong modulation. Such units were called radio reporters.[1] The radio reporters gave superior data on generator speed because there was less confusion as to the frequency of modulation. In fuzes, modulation of the carrier by the generator occurs due to filament modulation, at generator frequency, and due to plate production, at twice generator frequency.

Film records were first used to obtain generator speed data, but their use was later confined to those cases in which greater accuracy was necessary.

The film was placed on a Recordak Viewer to enlarge the trace to a size convenient for counting. Since a synchronous motor was used to drive the camera, the distance between sprocket holes could be used as a time scale. With these cameras, when the line frequency was 60 c, the time scale was $\frac{1}{30}$ sec per space between two adjacent sprocket holes. The line frequency during the run could be found by counting the number of cycles of the 1,000-c starting signal per frame space at various points of the trace. The average count was taken to be the value to be used for the run. On well-regulated power lines this scale was very accurate and convenient to use. When the line frequency was not constant enough, a 50-c tuning fork oscillator was used to light a neon bulb, which left a series of dots along one side of the film. This could be used as the time scale.

The generator speed at a given time was obtained by counting the modulation frequency over a short time interval, centered about the time in question. This frequency could then be converted to generator revolutions per minute as follows:

If the modulation was caused by filament ripple, as was usually the case, speed was determined by the formula

$$s = \frac{c \times 60}{t \times n},$$

where s = generator speeds in revolutions per minute,
c = number of cycles counted in time interval,
t = time interval in seconds, and
n = number of pairs of poles in generator.

If the modulation frequency were due to plate ripple from a rectified power supply, a factor of 2 would appear in the denominator, since full-wave rectification doubles the generator ripple frequency.

Because of harmonic content in the modulation, it was often difficult to know whether the generator voltage frequency was being counted or a multiple or submultiple of that frequency. Therefore, for accurate work on film, reporter units, in which the modulation was deliberately enhanced, were used.

Because film work was slow and hard on the eyes, phonographic methods of determining generator speed were developed. It was also found that the phonographic method would yield data in the case of units which had considerable noise and microphonic modulation, which would ordinarily make film work impossible.

Two methods were generally used. In the first, a good record was essential, as any harmonic content tended to cause a frequency lower than the true one to be recorded. The record was played back, and the output of the player was led to a General Radio frequency meter, whose output was led through a General Radio d-c amplifier to a recording milliammeter. The trace was a direct frequency versus time curve. Corrections were necessary to make up the time differences caused by a difference in line frequency between the place where the record

[redacted]

was made and where it was played. The 1,000-c starting signal was used to calibrate the milliammeter scale.

The second and most used method of determining generator speed[13] depended upon the ability to match a note on a record with that from an oscillator, either visually or aurally. Because the usual record of carrier modulation had a fairly rapid change in frequency (since the bomb and hence the generator were accelerating), accurate frequency determination could not be made from the original record. A re-recording was made, therefore, through an electronic switch,[30] which allowed the output of the recorder amplifier to reach the cutting head only at definite intervals, usually about 0.8 sec, and only for a very short time, usually about 0.2 sec. This recording sounded like a record of a series of distinct monotones, gradually changing in frequency. If the frequencies were very high, the original record would be played at half speed, while the re-recording was made. The new record was then played on a turntable, whose speed could be adjusted and played at full or half speed. The 1,000-c note was used for setting this speed, and the matching note was obtained from a standard oscillator in the radio building of the National Bureau of Standards.

The output from the record was led to a loudspeaker and one pair of plates of an oscillator (see Figure 3). The output of an audio oscillator (Hewlett-Packard 200B) was led to a single crystal earphone and to the other

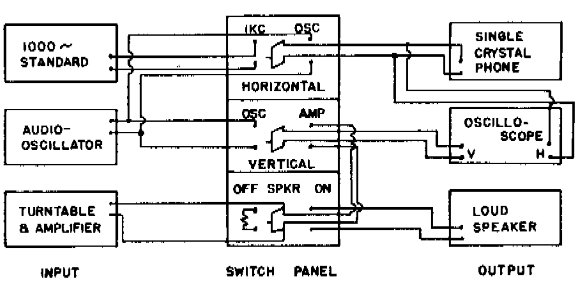


FIGURE 3. Block diagram of apparatus for determining generator frequencies.

pair of oscilloscope plates. The record was then allowed to play until a note was reached of which the frequency was to be determined. Here a stop kept the tone arm from traveling farther, and, because of the spacing of the notes, one note only would be played over and over again, as the arm hit the stop, jumped back a groove, and came to the stop again. The frequency of this note was matched by varying the frequency of the audio oscillator, until the two notes sounded the same and no beat notes could be heard. A Lissajous figure on an oscilloscope was used to improve the accuracy of match. An exact match would be indicated by a stationary figure, but since the frequency of the note on the record was changing, even though it sounded like a monotone, the attempt was made not to get a motionless figure, but one which moved only slightly.

When the frequency had been determined, the record was played through from the beginning. The time from the starting signal to the matching note was obtained by a stopwatch, several determinations being made. Since the frequency could be changed into generator speed very easily in a manner similar to that explained already, the use of this procedure led to the determination of points on a generator speed versus time curve. By the use of bomb velocity versus time curves, these data could be translated into bomb velocity versus generator-frequency data, and vane slip factor data could be obtained. This method was rapid and sufficiently accurate for engineering purposes. In the case of noisy or microphonic records, the ear could discriminate between the desired and the extraneous frequencies where an instrument could not.

While the ear could not determine whether the frequency was the direct generator voltage frequency or some multiple or submultiple, the general range of speeds could be obtained from film or phonographic records of reporter units on which the frequencies could not be mistaken.

8.2.13 Special Tests

ARMING TESTS

Because safety and arming data are of great importance to the users of variable-time [VT] fuzes, there had to be devised tests from which it would be possible to obtain data on the arm-

ing time and arming distance. Since the ballistics of the bombs were known, the problem reduced to that of finding accurately the time to arm of many units with various arming settings on various bombs.

Two ways of indicating arming were used. In the first, the unit was modified to function on arming, so that ground observation of arming time would be sufficient. The ways of obtaining function time, mentioned previously, then applied to these special tests.

The second way consisted of using units which would function normally but with modifications, such that the carrier modulation would be changed in some way at completion of mechanical arming. Reporter units could also be arranged in this way. A reporter unit, in which the transfer pin did not spring out of the slow-speed shaft and in which the plate circuit was shorted when the rotor contacts were in the armed position, would indicate arming by an interruption of the carrier, which lasted until the rotor contacts had turned out from under the stationary ones. If the filter condenser were not grounded until arming, an otherwise normal unit would indicate mechanical arming by a sudden cut off in modulation, followed by modulation at one-half the former frequency. With a short RC delay incorporated in the arming system, this shock would not trigger the fuze, which could then ride through to function on the target.

The use of T-2 arming delay units made this problem more complex, since safety considerations prohibited the use of VT fuzes set to function immediately after the operation of a delayed arming device whose arming characteristics were unknown. Such devices prevented the unit from emitting a carrier, until after the arming device had dropped off and the warmup period was over.

Since the fuze had to arm normally, even though shortly after the release of the T-2 device, it was possible from ballistic data, the generator speed versus time curve, and the arming setting of the fuze to determine the time at which the delayed arming device dropped off. The fuze was usually set to function on arming.

A special unit could have been used for very accurate determination of release of the delayed arming device, if more accuracy had been necessary. Such a unit would consist of a dummy fuze with an oscillator built into it, so arranged that the oscillator would be cut off at the release of the delayed arming device. A laboratory test would provide the field crew with the carrier frequency of the oscillator, so that it could be tuned in immediately, allowing the delayed arming device to be set for short arming periods. The determination of arming time would then be the same as that of function time, previously described.

Train Tests

In order to test the mutual effects of VT-fuzed bombs, several tests were made, in which bombs were dropped in trains with various intervalometer settings. Some of these were made with HE-loaded bombs, others with inert-loaded bombs. In most of these tests, one or more of the fuzes in each train was set to function on arming and after the other fuzes had armed. In this manner it was made certain that there would be at least one early function, and the stability of the other fuzes in the train could be observed.

Data on the time of early functions were obtained in several ways. The chief observer, who handled the release switch, would put short peeps of the 1,000-c note on the record of carrier modulation by momentarily pressing the switch at each function. He also used several stopwatches to obtain the times of such functions. A camera was also mounted in the plane, and the frames from the time of the first function to those of the other functions were counted. The relative function times could be obtained from this information as the rate at which the film was exposed was known.

Such film would also show the relative position in the horizontal plane of any functions occurring close together. A follow-down camera would show these from another angle.

Proper functions over the water were sometimes hard to locate, because the smoke or flash from one would hide another, and, in the case of HE-loaded bombs, the curtain of spray thrown would obscure the impact positions. In such cases it was often necessary to rely on

[redacted]

visual estimates of the range of function heights for a closely spaced train.

Dive Tests

In order to obtain data on the performance of VT fuzes in dive bombing, some tests were made in which bombs were released at various speeds and at various angles of dive. A camera,

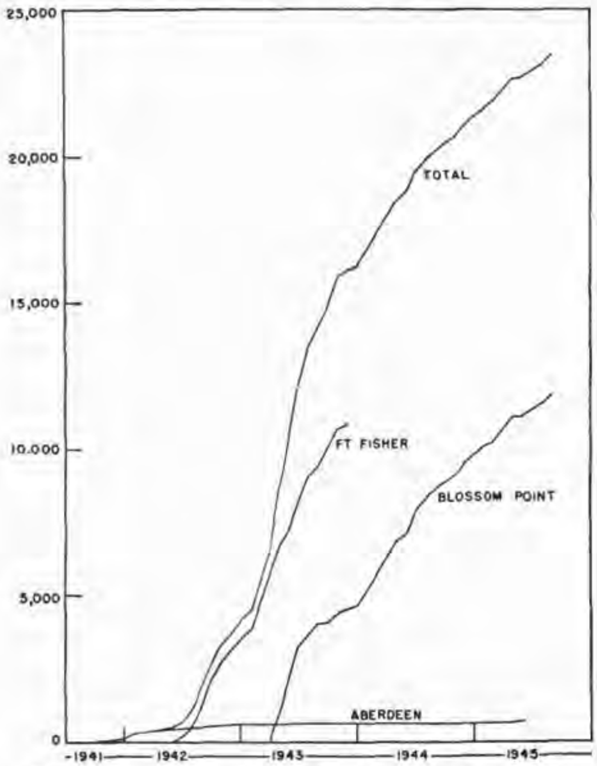


Figure 4. Accumulative number of rockets fired from stationary launchers.

in which a focal plane shutter was operated by hand while a rotating shutter was continuously driven by a motor, was used to photograph the path of the plane. The variations in plane speed, dive angle, and point of release led to the abandonment of this method in favor of simulated dive tests. In these tests a pilot flew a level course at such an altitude and speed that the approach of the bomb to the target was the same as it would have been if the bomb had been released under certain dive bombing conditions. The impact angle of the bomb was obtained by the three-dimensional analysis method already mentioned. The use of a high-speed camera, combined with the others, made possible the determination of terminal velocities.[27]

Determination of Time Lags

One of the questions which arose during the testing program was whether the spotting charge appeared at the same place as where the fuze function occurred. Static tests were made in which a photoflash bulb of known time

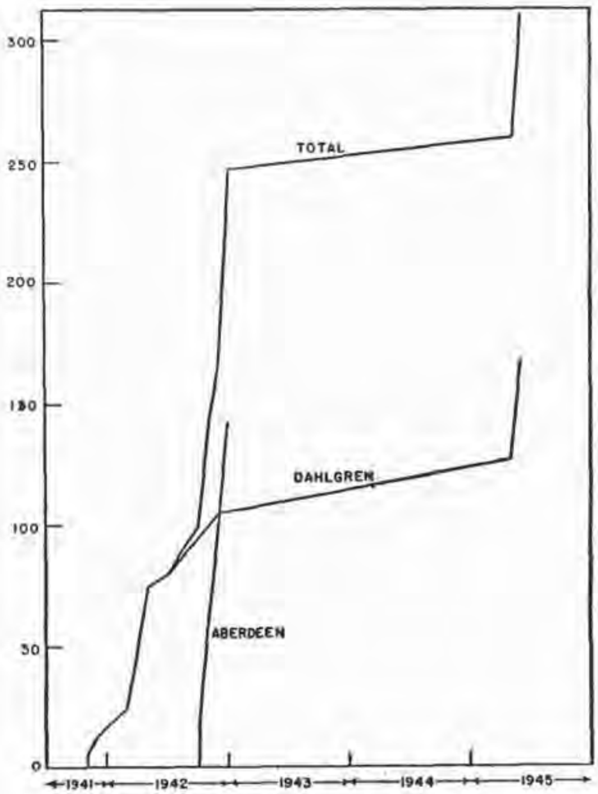


Figure 5. Accumulative number of rockets fired from airplanes.

characteristics was fired at the same time the detonator was fired. The explosion of the spotting charge was photographed by a high-speed camera, and the time between firing and the appearance of the flash was obtained.[12] It was found that the time taken for the explosion to travel down the tube from the fuze to the tail of the bomb was of the same order of magnitude, 5 msec, as the time for the bomb to travel its own length at the usual release conditions and function heights, so that the flash would be approximately where the fuze was at function. It is not known how the speed of puff travel is affected by the bomb velocity. It is also not known whether the HE burst would occur exactly where the spotting charge burst does.

FIGURE 6. Range for high-angle rocket firing at Fort Fisher.

The position of the spotting charge function is close enough to the expected position of an HE burst to be used for all but a few limited applications of the fuze.

8.3 THE FIELD TESTING OF ROCKET FUZES

8.3.1 Introduction

Although radio proximity fuzes for rockets were developed largely for air-to-air or air-to-ground use, most of the experimental data required during development could be, and were, obtained by firing fuzed rockets from launchers located on the ground or on ground-supported towers. As required, these data were supplemented by data obtained from tests, some of which were quite extensive and which were performed at Aberdeen, Dahlgren, Eglin Field, and Inyokern, in which rockets were fired from airplanes. In both types of firing, a large pro-

FIGURE 7. View of Blossom Point, looking west from the firing tower.

FIGURE 8. View of east and west ranges, Blossom Point.

portion of the rockets were inert except for a spotting charge to indicate functioning of the fuze.

Chronologically, but with considerable overlapping, the largest volume of firing of rockets under the direct supervision of Division 4,

FIGURE 9. Smaller concrete magazines at Blossom Point.

NDRC, was done first at the Aberdeen Proving Ground, then at Fort Fisher, North Carolina, and finally at the Blossom Point Proving Ground, which was located on the Maryland shore of the Potomac River about 40 miles south of Washington. In Figure 4 accumulative

FIGURE 10. Large concrete magazine at Blossom Point.

[redacted]

curves of rocket rounds fired from stationary launchers at the various proving grounds are shown. Similar curves for rounds fired from airplanes, not including those fired at Eglin Field and Inyokern in tests conducted by the Armed Services, are given in Figure 5.

ward the west and northwest from the top of the firing tower at Blossom Point. Figure 7 shows the main group of buildings and Figure 8 shows the west range and part of the east range. A tow target is suspended between the poles of the west range. The poles on the right

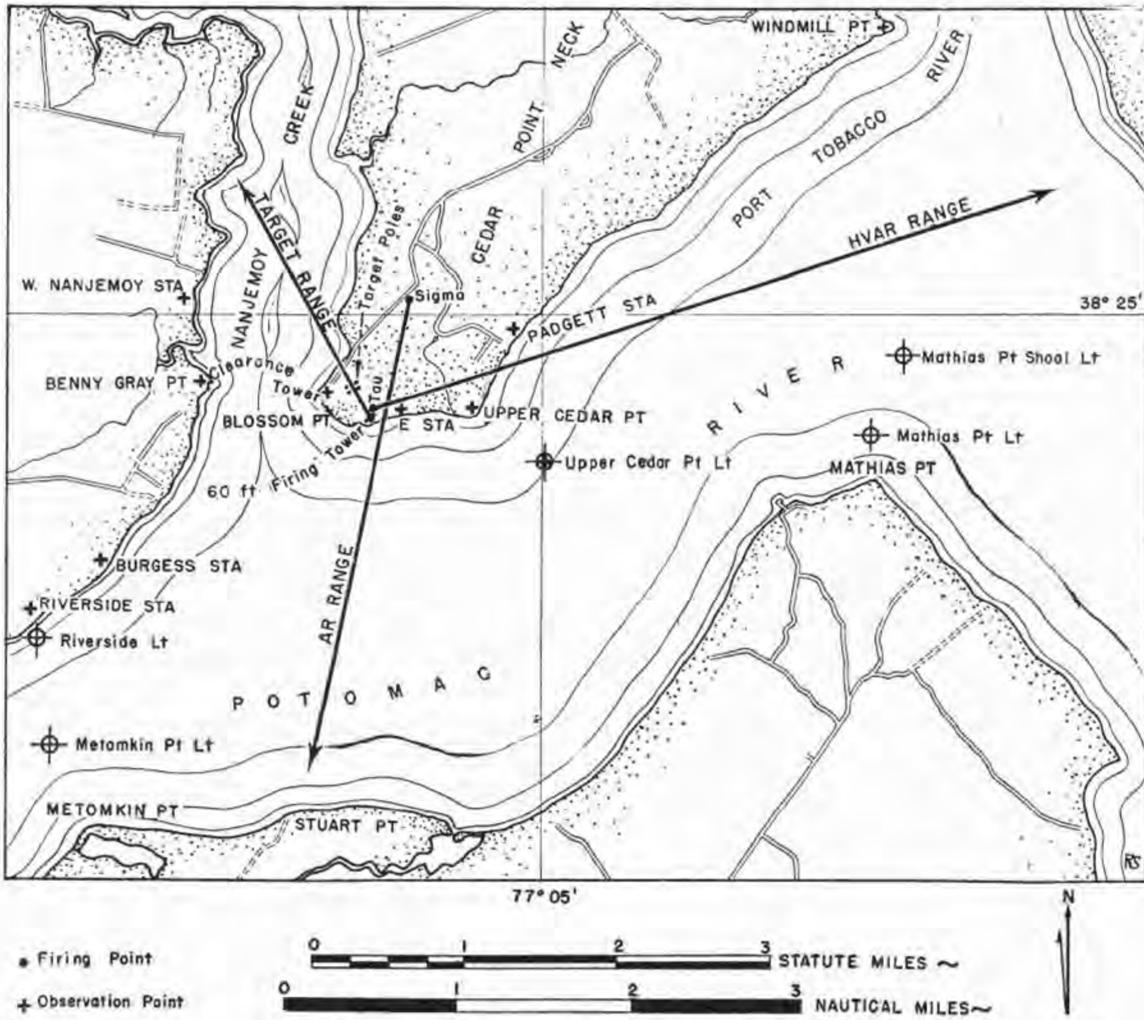


FIGURE 11. Rocket ranges at Blossom Point.

Figure 6 is a photograph of the range used for high-angle firing of rockets at Fort Fisher. The main laboratory building appears at the bottom of the picture and the balloon hangar at the top. As indicated by dust clouds, a rocket had just been fired from a mobile launcher when this photograph was taken. The beach which appears in the upper left-hand corner is on the Atlantic Ocean.

Figures 7 and 8 are photographs taken to-

are on the east range, which was used for the test firing of photoelectric fuzes. The three concrete magazines at Blossom Point are shown in Figures 9 and 10.

A map of the Blossom Point range is shown in Figure 11. The directions of fire often used are indicated, together with the locations of navigation lights which were often used as reference points in night firing.

Details of instruments used in visual and

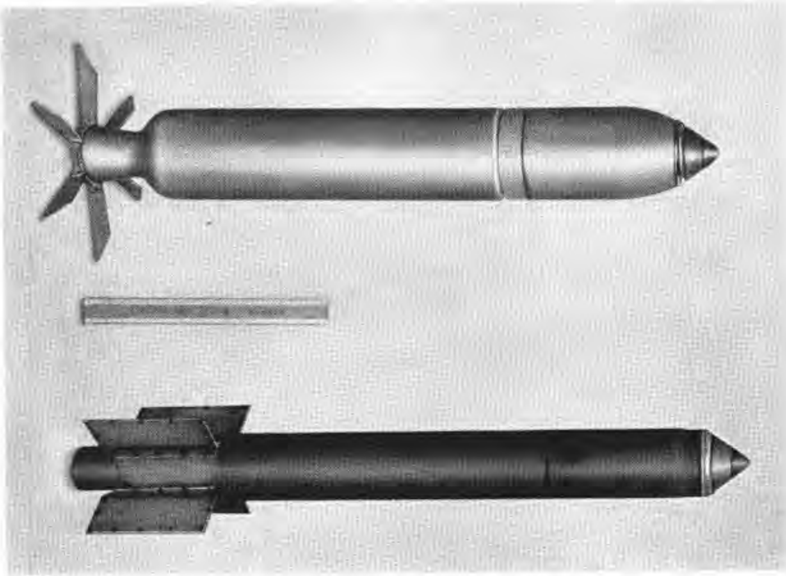


FIGURE 12. Budd 4.5-in. rocket (top), Cenco 3.25-in. rocket (bottom), both with T-5 fuzes.

photographic observations of rockets in flight, and of their limitations, are given in reference 7. Where possible, duplication of the information given there has been avoided in the present chapter on the testing of rocket fuzes.

8.3.2 Rockets and Launchers

In the chronological order in which the rockets became available, the rockets used in fuze testing and some of their characteristics are given in Table 2. Some of the rockets were fired with a variety of propellent charges, but in general the table gives characteristics for only those combinations most frequently used and is intended to give a general picture of the variety of test vehicles available. The availability of rockets of rather widely different characteristics made possible a greater variety of test conditions. Special values of acceleration or maximum velocity could be provided as needed to test fuze components under conditions more severe than expected in service. Also airspeeds could be obtained when firing from a ground launcher equal to those expected in firing from airplanes.

The ballistic characteristics are functions of temperature and other conditions. The values are representative of firings in summer.

TABLE 2. Rocket characteristics.

						Fuzed rocket					
	Diameter		Head	Unfuzed rocket		Burning		Max		Flight at 45° quadrant elevation	
Rocket	motor (in.)	head (in.)	wt (lb)	length (in.)	weight (lb)	distance (ft)	Time (sec)	vel. (fps)	Accel. (g)	Range (ft)	Time (sec)
Cenco	3.25	3.25		32	20	40	.12	675	175	10,000	30
M-9, etc.	4.5	4.5		33	38	50	.20	925	150	12,500	33
AR	3.25	3.5	4	54	39	600	1.0	1,500	50	18,000	37
	3.25	3.5	15	56	50	500	1.0	1,150	35	16,000	34
	3.25	5.0	37	62	72	450	1.0	825	25	13,000	30
HVAR	5.0	5.0		66	123	800	1.0	1,375	45	29,000	44
T-83	4.5	4.5		72	93	250	0.4	950	75	18,000	35

As explained in Chapter 1, the development of the T-5 rocket fuze for the M-8 rocket was carried out concurrently with the development of the rocket. This meant that no field testing could be done until the rockets were available unless some interim method could be devised. To this end a simple inexpensive rocket was designed and manufactured solely for the purpose of carrying out experimental tests of the fuze. This rocket was designed to give essentially the same acceleration characteristics as

FIGURE 13. Four-rail rocket launcher, Fort Fisher.

the M-8 rocket was expected to have. It had a $3\frac{1}{4}$-in. body. The first models were built in the National Bureau of Standards shop and later the Central Scientific Company manufactured sufficient quantities for the field tests. It was commonly referred to as the Cenco rocket. Details of the construction are not included here but may be obtained from reference 40. Some testing was done with British rockets but their acceleration characteristics were so different from those of the M-8 rockets that their usefulness in testing T-5 fuzes was very limited. A Cenco rocket with a T-5 fuze is shown in Figure 12. A multigrain propellent charge of solvent-extruded double-base powder having a total weight of about 2.65 lb was normally used in this rocket.

The Cenco rockets were usually fired from two-rail or from four-rail launchers which were fabricated from iron pipes and other iron pieces in the shops of the National Bureau of Standards and of the Aberdeen Proving Ground. Figure 13 is a photograph of a four-rail launcher at Fort Fisher mounted on a truck chassis.

Two-rail launchers were more simple in construction, but, since they were merely a pair of rails upon which the rocket slid when fired, they provided no restraint for the upper half of the rocket, which therefore could, and sometimes did, lift up from the rails at the forward end and leave the launcher at a higher angle of elevation than that of the launcher.

Figure 14 is a photograph of the forward end of a two-rail launcher, constructed, in this case, of two lengths of railroad rails. This launcher was constructed at Fort Fisher at a time when rocket motor blowups on the launcher were so frequent, sometimes every other round, that launchers constructed of pipes, which are usually destroyed in such a motor failure, were impracticable. This railroad rail launcher suffered many motor failures without suffering sufficient damage to prevent its continued use.

The M-8 rockets became available in quantities sufficient for the field testing of fuzes about the time that laboratory development of the

FIGURE 14. Two-rail launcher and target range, Fort Fisher.

fuze was completed. They were then used for testing production models of the fuzes, and the Cenco test rocket was accordingly abandoned.

The M-8 series designation indicated HE loading, and these rockets had inert-loaded counterparts which bore a series of M-9 designations. There was no unanimity in the proper designation of such rockets having neither inert nor HE loading, and such empty rockets were

[redacted]

variously designated as M-8, M-9, empty M-8, empty M-9, etc. There were other variations in rockets, such as manufacture, fin design, and powder trap design, which had a bearing on fuze performance (see Chapters 5 and 9).

All these Army rockets had folding fins, as shown in Figures 12 and 15. Toward the end of World War II, the rockets of this type were supplied with attachable fixed fins and were then designated as T-74 with no differentiation with regard to loading.

FIGURE 15. Army 4.5-in. rocket and pipe launcher, Blossom Point.

The 4.5-in. rockets with folding fins could be fired from ordinary iron pipes of suitable inside diameters (the inside diameters of most of the launching tubes used lay between 4.6 and 4.7 in.) such as the one of which the breech end is shown in Figure 15. Consequently the construction and mounting of launchers of any desired length for these rockets was a comparatively simple matter.

At the time when tests of fuzes on Navy aircraft rocket [AR] and high-velocity aircraft rocket [HVAR] started, standard Navy launchers, such as the one shown in Figure 16, were already available and were very suitable for proving ground use.

Additional details of rocket launchers and firing procedures will be found, in the form of informal notes, in reference 33.

8.3.3 Loading and Assembly of Fuzes and Rockets

The assembly of rocket fuzes was very similar to that of bomb and mortar fuzes as described in Sections 8.2.4 and 8.4.3 and does not need to be given in detail. Further details on loading, assembly, and storage procedures are given in reference 32.

Except for the T-5 and T-6 fuzes for which very satisfactory black powder spotting charges were provided as a standard component by Picatinny Arsenal, the spotting charges were the same cartridges of a mixture of potassium permanganate and magnesium powders as were used in bomb and mortar shell fuzes. To minimize fragmentation of the rocket head, which was a hazard when early malfunctions occurred, the rocket heads were often provided with four 1-in. holes to facilitate the emission of flame and to reduce the pressure inside the head developed by the explosion of the tetryl and spotting charge. The 3.5-in. AR heads which appear in Figure 17 are so drilled. Similar holes may be seen in the photograph of the Cenco rocket in Figure 12.

FIGURE 16. HVAR rocket on Navy launcher, Blossom Point.

The propellant for many rounds of Cenco and

FIGURE 17. Groups of fuzed projectiles, Blossom Point.

FIGURE 18. Fuzed AR and HVAR rockets; firing tower, Blossom Point.

Army rockets was installed at the proving grounds. Since these rockets are obsolete, reference is made to the notes given in reference 32 for details of loading and assembly. The Navy rockets were fired as received, except that particular care was taken to insure tightness of the tail assembly, as described in the notes referred to above. Figure 18 shows a group of fuzed AR and HVAR rockets at Blossom Point ready to be taken to the firing point.

8.3.4 Classification of Field Tests

The types or classes of information desired and obtained from proving ground tests on rocket fuzes are listed below. Reference is made to the sections in which the methods used to obtain particular types of data are described.

1. Fuze quality (Section 8.3.5).
2. Fuze sensitivity and burst surface (Section 8.3.6).
3. Fuze arming distance (Section 8.3.7).
4. Causes of fuze malfunctions and effectiveness of remedies (Section 8.3.8).
5. Exterior ballistics of rockets as affecting fuze design and performance (Section 8.3.9).

8.3.5 Tests of Fuze Quality

GENERAL PROCEDURE

Tests of fuze quality consisted in firing a sufficient number of rounds in some particular manner to determine the proportions of proper and improper functions. The number of rounds fired, when feasible, and the significance of the results were determined by standard statistical considerations (see Chapter 9).[4, 36, 39] The most commonly used firing methods were (1) at a mock-aircraft target from a stationary launcher, (2) high-angle firing tests against ground or water targets, and (3) firing from an airplane in flight.

TARGET TESTS (HORIZONTAL FIRING)

In most target tests efforts were made to simulate conditions of air-to-air tactics. The rockets were fired almost horizontally at a mock-airplane target from a launcher mounted on a substantial tower.

Since the fuzes are sensitive to approach to, or departure from, a reflecting surface it was necessary to select the firing conditions so that ground reflection would not interfere with or mask the aircraft target signals. If the fuzes were fired horizontally over completely level and electrically homogeneous terrain, they would receive no firing pulses because there would be no relative vertical component of velocity between fuze and terrain. While this situation cannot be realized physically, it was found possible to choose terrain and height and elevation of trajectory such that ground reflection signals would be negligible.[3] Such signals may arise not only from relative velocity between ground

and target but also from sudden variations of the reflection coefficient of the surface under the trajectory. (Changes in reflection coefficient

FIGURE 19. Horizontal target range, Fort Fisher.

would change the load on the oscillator in the fuze.) It was found that, with a target mounted 50 ft or more above ground and a launcher about 1,000 ft away and at approximately the same elevation, ground reflection signals due to relative velocity were negligible. The elevation of the launcher was adjusted so that the peak of trajectory was between the arming point and the target. This arrangement[5] permitted very rapid firing under conditions which were essentially reproducible at any time and had other advantages which are discussed in Section 8.3.6.

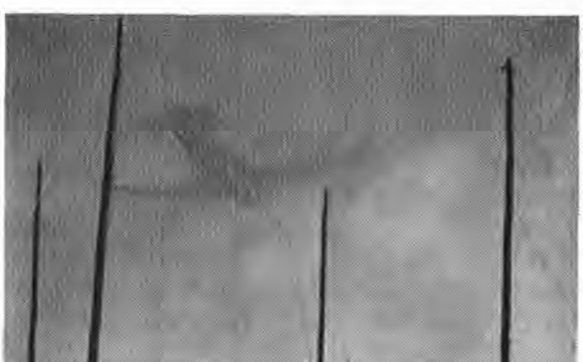


FIGURE 20. Mock-plane target, Fort Fisher.

The first range of this type was set up at Fort Fisher. The launcher was about 40 ft above ground, the target about 60 ft above ground and 1,000 ft from the launcher. The target was constructed of well-bonded chicken wire with wood supports. Figure 19 is a general view of the range. Figure 20 is a close-up view of the target. Notes on the method of suspending this target are given in reference 33.

A view of the similar range at Blossom Point is shown in Figure 8, a diagram of this range in Figure 21, and a photograph of the 60-ft tower may be seen in Figure 18. The dimensions

T Target
S Side camera station
FT Firing tower
C Firing point camera, 50 ft above ground and directly under projector
Target poles enclosed an area 100x125 ft

FIGURE 21. Diagram of target range at Blossom Point.

of the target, which was usually suspended 70 to 75 ft above ground, are given in Figure 22.

As indicated in Figure 21, camera and observing stations were located in the towers directly below the launcher (with armor plate beneath the launcher) and at side stations located on lines normal to the trajectory at the target. A view of the side observation station at Fort Fisher is shown in Figure 23.

While visual observations were sufficient for tests of fuze quality, moving pictures of the spotting charge burst were usually taken in addition. These supplied the more accurate data needed for determining fuze sensitivity

and burst surface (see Section 8.3.6). Notes on observational procedure will be found in reference 34.

High-Angle Firing

When information on the performance of a fuze under more severe conditions was desired, the fuzed rockets were fired from the ground to function upon approach to water after a long flight. Such a test was more severe, since there was more opportunity for malfunctions to occur caused by generator failure, rocket vibration, and fuze microphonics. The angle of elevation

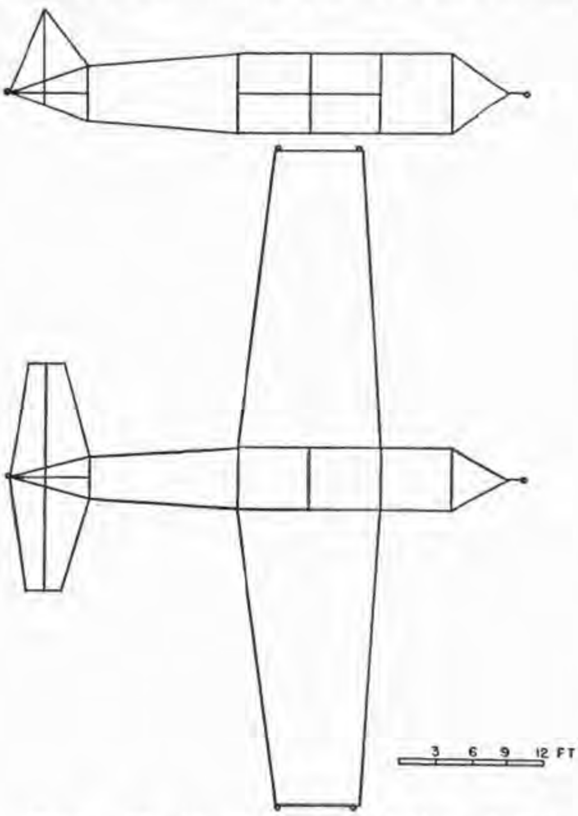


Figure 22. Diagram of mock-plane target (Blossom Point).

was raised sufficiently so that at arming the fuze would be sufficiently far from the ground not to be caused to function by the radio waves reflected from the earth. Much firing was done at elevations of 65 or 70 degrees.

In high-angle firing, visual and photographic observations were made from stations suitably located. The locations of stations often used at Blossom Point are shown in Figure 11.

Figure 23. Side observation station, Fort Fisher.

Firing from Airplanes

While the maximum airspeeds to be expected in firing HE-loaded rockets from airplanes could be attained in launchings from ground locations by the use of lighter rockets, other conditions obtaining in actual service use, such as the initial airspeed and vibration of an airborne launcher, could not be readily duplicated. Consequently, from time to time tests were made in which fuzed rockets were fired from airplanes, usually for function upon approach to land or water. Reference 20 gives the results of a typical test of this type at Dahlgren. Reference 22 gives the results of a test at Aberdeen.

Carrier Indications of Fuze Performance

As an aid in determining the causes of fuze malfunctions, for nearly every round fired the presence or absence of fuze carrier was determined, and for nearly all rounds of generator-powered fuzes, phonograms or cathode-ray oscillograms of carrier modulation were obtained. The circuits used are described in detail in Section 8.4.3. Figure 24 is a photograph of the radio receiving and recording equipment used at Blossom Point.

Carrier modulation records gave evidence of microphonics, generator bearing seizure, and generator frequency. To determine generator frequency the approximate values to be expected had to be known, since filament voltage ripple produced fundamental modulation fre-

quency and plate voltage ripple twice fundamental, and either might predominate. To obtain unambiguous generator speed values, reporter units were used on rockets as discussed for bomb tests. Analysis of the records was as discussed in Section 8.2.12.

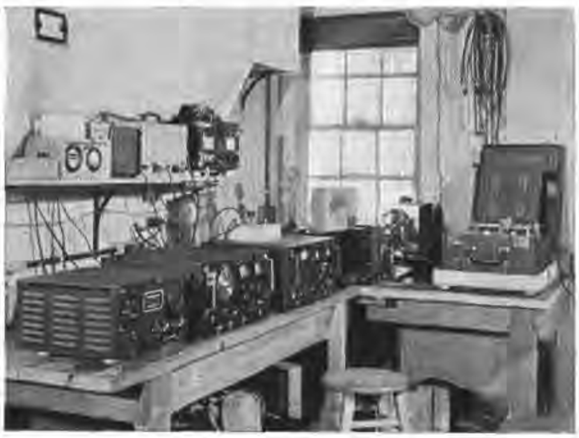


FIGURE 24. Radio receiving and recording equipment, Blossom Point.

8.3.6 Determination of Fuze Sensitivity and Burst Surface

GENERAL CONSIDERATIONS

In order to correlate laboratory data on the electric characteristics of fuzes with expected Service characteristics, many tests were performed to determine the probability and locus of function of fuzes passing or approaching specified targets at measured speeds and distances. Such data were necessary in order to assess the effectiveness of a given fuze for a given tactical application. An example of such an assessment is presented by a series of reports of the Applied Mathematics Panel (references 19, 20, and 21 of Chapter 1).

WATER-APPROACH TESTS

One of the simplest methods, and one often used, to determine the sensitivity characteristics of a given type of fuze is to measure the height of function upon approach to water. The reflectivity of the target (water) is essentially constant at a given location, and the variation in sensitivity with aspect can be investigated by varying the angle of approach, giving due allowance to the varying vertical component of the approach velocity. In such tests, assuming the ballistics of the fuzed rocket are known (cf. Section 8.3.9), the proving ground is called upon to provide the photographic records from which the height of function over water can be determined.

The determination of height of burst was often combined with the obtaining of other types of information, such as afterburning characteristics (cf. Section 8.3.8) and consequently was sometimes done in daylight, sometimes at night.

The method of obtaining function heights in daylight was the same as that for obtaining function heights of bomb fuzes, except that aiming circles were used to obtain triangulation data. Two or more observation stations on surveyed base lines as long as were necessary or practicable were used.

At each station were an aiming circle operator and a 16-mm moving picture camera operator. Each station was provided with telephone or radio communication with all other points of operation.

The distance of the point of function from each camera was obtained by use of large plotting boards. Then since the effective focal lengths of the lenses used had been determined by photographing scales of known lengths at known distances, as described in Section 8.2.9, the measured heights of function on the films could be translated into actual heights. The measured distance on the film was the distance between the splash at impact and the first visible flash of the spotting charge. Since the distance from camera to function was always large in comparison to the height of the camera above the water surface, the fact that the splash was not directly beneath the point of function produced no significant error.

At night the splash did not appear, and the method of determining the height of function consequently was somewhat different. Still cameras, instead of moving picture cameras, were used to photograph the flash of the spotting charge and lights whose positions and heights above water were accurately known.

[redacted]

The reference lights were either navigation lights or temporary lights placed at intervals on a line crossing the area in which impacts were expected.

To reduce the number of films used and developed in such tests, special cameras were designed and constructed. These cameras carried 8x10-in. films in holders which could be racked down across a horizontal focal plane slit. As many as 15 rounds could be photographed on one film with such a camera.

The position of function was determined by triangulation on a range plotting board, the azimuth of the flash at each station being determinable from its position on the film with respect to the reference lights. By trigonometrical methods, the apparent height of flash with respect to the reference lights could then be translated into actual height of function above the surface of the water. A value for the height of function was obtained for each camera and the average agreement in these values was of the order of $\frac{1}{20}$ of 1 per cent of the distance from camera to function.

TARGET TESTS

While water-approach tests gave data on the sensitivity of the fuze with respect to a large horizontal reflecting surface, target tests were required to determine whether the position of the function with respect to an airplane was favorable for producing effective damage. When sufficient rounds were fired, the positions of burst obtained defined a surface, or rather surfaces (because of the radiation lobes of the fuze), on which function was most probable as a fuze passed the target.

Before horizontal ranges came into use, such tests were performed, mainly at Fort Fisher, by firing fuzed rockets at targets supported from balloons, using the mobile launcher shown in Figure 13. The burst of the spotting charge was photographed from two stations, one of which was approximately directly beneath the target, the other off to the side. A camera was also placed near the firing point at times. Especially built fixed-focus cameras using 8x10-in. plates and equipped with azimuth and elevation scales were used in these tests. The target was generally an array of crossed dipoles, the array being 40 ft long. Figure 25 shows a burst on such a target. The balloon used for supporting this type of target is shown in Figure 26 in its hangar at Fort Fisher. The known length of the target was a useful parameter in determining the position of function with respect to the target.

Because the target position was continually changing, and dispersion was large because the launcher had to be short to be mobile, these tests were time consuming and wasteful of ammunition. Many rockets passed the target at distances too large to permit the fuze to function. With the installation of the ranges for horizontal firing described in Section 8.3.4, balloon-supported targets were abandoned and the testing greatly expedited. Since the target was fixed, the launcher had to be only slightly adjustable and consequently could be made sufficiently long (30 or 40 ft) to reduce materially the dispersion of fast-burning rockets. Considerable control of the position of the trajectory with respect to the target was then possible. Moreover, the aspect of the target, which was constructed to have approximately the reflectivity pattern of an airplane, could be readily changed as desired. Still another considerable advantage was the fact that the camera positions were fixed and could be located in such positions (directly beneath the launcher and on a line normal to the centerline of the range at the target) as to reduce to a minimum the operations required to determine the position of function.

8.3.7 Determination of Arming Distance or Time

All proximity fuzes were designed to arm at a distance determined by various considerations of safety and tactical use. Arming tests in the field were performed to determine the reliability of arming mechanisms under standard and marginal conditions and to obtain data from which the statistical distribution of arming times, or distances, could be computed.

The arming arrangement was mechanical or electric (RC arming) or a combination of the two. With any of these arrangements, the

determination of the time of completion of the mechanical arming process was comparatively simple and direct. The time to completion of RC arming was more difficult to determine.

Photographic Method (Mechanical Arming)

In the most direct, and most frequently used, method for investigations of mechanical arming, the fuze was modified to function upon completion of mechanical arming, mounted on a rocket and fired in the usual manner. The time at which the fuze functioned was then measured by stopwatch, or the time and locus of function were determined photographically. Reference 14 includes a description in detail of a method for obtaining indications of a number of arming functions on one film or plate and for interpreting the results.

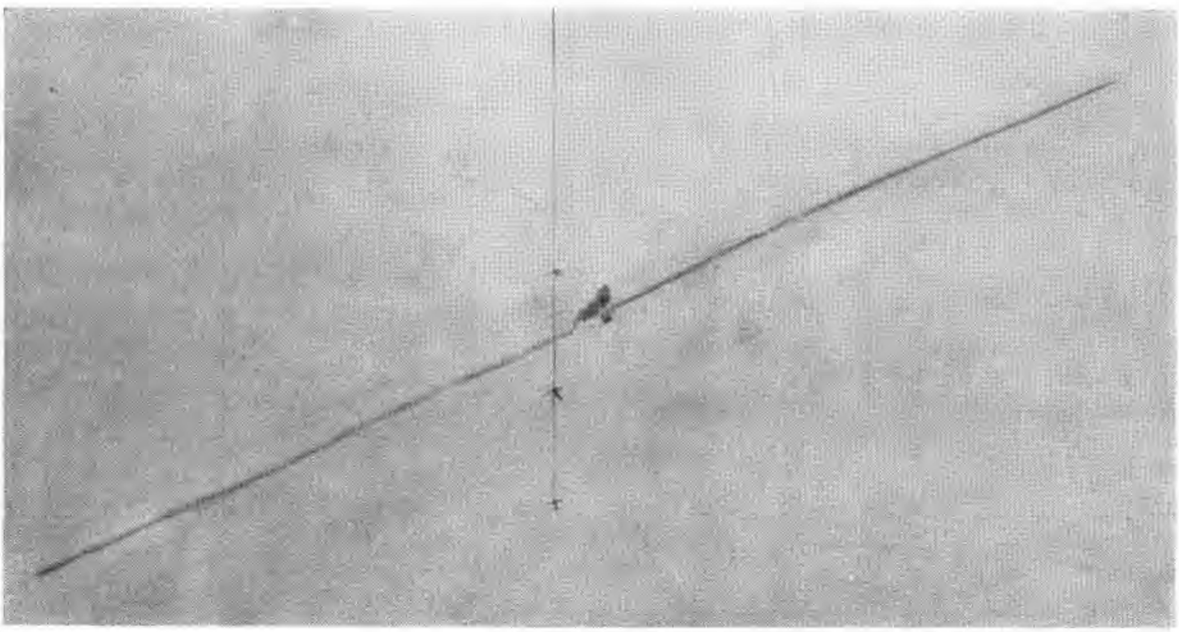


Figure 25. Rocket with smoke tracer and function on array of crossed dipoles suspended from balloon, Fort Fisher.

Carrier Indication of Mechanical Arming

A radio method of measuring the time to completion of mechanical arming was used where feasible, since it had the advantage of not destroying the fuze at arming and so allowing the determination of arming time to be combined with other types of testing. This method could be used only with generator-powered fuzes. It involved modifying the fuze so that at the completion of mechanical arming a recognizable change in the modulation of the carrier would occur. The fuze wiring was changed so that the detonator rotor contacts were in the filter and rectifier circuit. At arming, then, a change in amplitude or frequency of modulation or both occurred and was recorded on an oscillograph or sound-recording equipment connected to the output of a radio receiver. The time of launching was obtained on the same record by mounting a switch in a 1,000-c circuit on the launcher in such a position as to be opened or closed by a fin or other part of the rocket as the rocket started to move forward.

Since the time to arming was often too short to allow the carrier to be tuned in with a receiver of normal selectivity, broad-band receivers (made by Zenith) were often used. These receivers have a flat frequency response over a range of ± 3 mc. Their main drawback is the absence of an r-f stage with consequent possibility of direct interference through the i-f stages. In addition, they are inherently less sensitive than receivers of greater selectivity

and consequently could not always be used when desired.

RC Arming Measurements

A possible method of determining the time or distance to completion of RC arming is to vary the distance between launcher and target and obtain the distribution of duds and proper functions as a function of this distance. Some experiments of this type were performed by firing from airplanes to ground as described in this section. Otherwise there was no satisfactory

FIGURE 26. Balloon in hangar, Fort Fisher.

method of varying the distance between the launcher and a physical target. Instead, in horizontal firing, a portable sweep-frequency transmitter was used to supply a triggering pulse to fuzes in flight at various positions along the trajectory.

Because of rocket dispersion, the power of the transmitter had to be greater than would have been necessary if the distance of passage had been constant. Consequently, if the transmitter had been left in continuous operation, the position at which the fuze first received a signal of firing intensity would have been indefinite and could have been up to 200 ft short of the point of passage above the transmitter. For this reason, a time switch, consisting of a thyratron and associated RC circuit initiated by a rocket-operated switch on the launcher, was used to key the transmitter at the time when the rocket was directly over the transmitter. The interval of time between launching and operation of the transmitter was measured automatically by means of a time clock.

It was not possible to apply continuous signals or a series of signals because if a pulse of sufficient magnitude to fire the thyratron were received by the fuze before arming was complete, the detonator-firing capacitor would "dump" the charge and the arming cycle would start over (see Section 3.3.6). Thus the pulsing method of measuring arming times gave only a "yes" or "no" indication on each round fired. Large numbers of rounds had to be fired to obtain reliable arming time data.

This arrangement was used in arming tests of the T-30 fuze on HVAR and AR rockets. Because of the cessation of hostilities these tests were not so extensive as originally planned. A progress report on the results is given in the Bibliography.[38]

Function, No-Function Tests at Various Slant Ranges

In order to test arming characteristics under Service conditions, fuzed rockets, inert or HE-loaded, were fired from planes at various slant ranges. By determining the ranges of firing photographically, the dividing line between duds and proper functions could be bracketed and the arming distance determined to a degree of certainty dependent upon the number of rounds fired. This method was applicable to the testing of fuzes of any type with any type of arming.

8.3.8 External Causes of Fuze Malfunctions

Introduction

Throughout the development of proximity fuzes for rockets, much field testing was directed toward investigating causes, external to the fuze, of malfunctions and the effectiveness of remedial measures devised to minimize such effects. Propellant afterburning and instability of rocket parts were particularly troublesome. Other factors studied were the effect of temperature upon setback, upon which arming depended, the effect of raindrops upon fuze performance, and the effect of rocket spin upon the arming of the T-5 and T-6 fuzes.

Investigations of Afterburning

Afterburning may be defined as the delayed burning of remnants of propellant or other combustible material which, for one reason or another, remain in the combustion chamber after main burning has ceased. (See Section 9.2.2.) The ionization produced by afterburning may cause malfunctioning of the fuze. (See Section 2.13.) Numerous field tests were devoted to studying the effect with many fuze-rocket-propellant combinations.[24, 38]

Much of the firing in these investigations was done at high angles and at night, in order that visual or photographic observations of afterburning might be correlated with observations of the locations of fuze functions.

A considerable accumulation of data was usually required before the incidence of malfunctions caused by afterburning could be differentiated from the incidence of malfunctions resulting from other causes. If afterburning was observed to occur only in the first part of the trajectory, the observed distribution of malfunctions in the rest of the trajectory could be extrapolated back into the afterburning region and the number of malfunctions due to other causes in this region subtracted from the total in this region to give a residue, the major portion of the total in such a case, attributed to afterburning. In other cases the analysis and interpretation were less straightforward and consequently less satisfactory.

As was to be expected from the frequency selectivity characteristics of the fuzes, intense afterburning was not necessarily accompanied by a high incidence of malfunctions. This was supported by static tests in which the pulses produced in the output circuit of the fuze by afterburning were recorded as cathode-ray oscillograms and correlated with simultaneously obtained moving pictures of the actual phenomena occurring and with performance in the field.[18] In general, it was found that a triggering flame was always a visible flame, but that all flames did not necessarily give rise to transients capable of triggering the fuze.

Figure 27, a typical set of photographs from night-firing tests, illustrates the great variations in afterburning phenomena encountered. The M-9 rockets were used in these rounds. The appearance of main burning also differs markedly with different propellants, as illustrated in Figure 28.

Effects of Rocket Structure

At one time or another almost every possible source of mechanical or electric instability in rockets was suspected and investigated as a cause of fuze malfunctioning. The method of investigation was the obvious one of statistically analyzing the incidence of malfunctions before and after making a modification in the rocket designed to eliminate the suspected source of triggering pulses. As examples, studies were made of the effect of electrically bonding the joint between head and motor, of the effect of electrically bonding the joint between folding fins and motor (leaving the fins still movable), of the effect of welding the fins rigidly in the open position, of the effect of making the trap structure more rigid, and of the effect of rocket spin (see Chapter 9 and reference 21) upon fuze performance.

The studies of fin structure led to a recognition of the necessity of inspecting the locking action of folding fins and to the design of a crimping tool which was used to make the locking action of individual fins more positive where necessary. This tool became a standard service item and was provided for use in combat areas.

Effect of Propellant Temperature upon Arming

Since the arming of rocket fuzes depends upon acceleration, and acceleration is affected by propellant temperature, tests were made to determine whether the arming mechanism would operate properly at the extreme service temperatures of the rockets. The fuzes were either arranged to function on arming or the incidence of duds with normal fuzes at the extreme temperatures was investigated. In these tests the rocket motors were first brought to the desired temperature in thermostatically controlled chambers. They were removed and fired quickly before the powder temperature changed appreciably. A typical test of this type is described in reference 16.

[redacted]

Effect of Raindrops upon Fuze Performance

Tests on the performance of fuzes, with and without plastic shields, in rain and in clear weather revealed that impact with raindrops could cause malfunctions the incidence of which could be reduced by the installation of plastic caps.

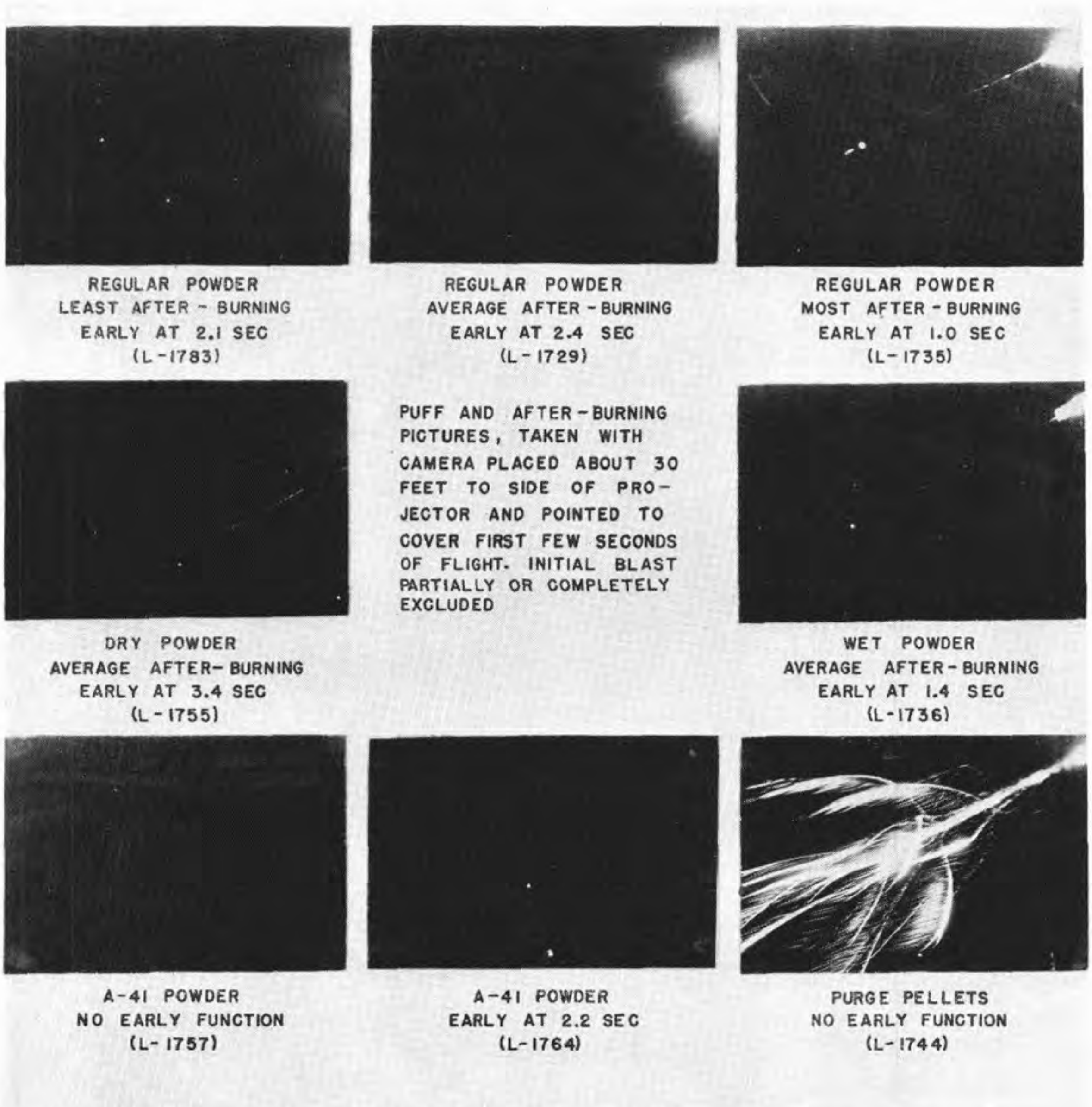


FIGURE 27. Afterburning with various propellants, M-9 rocket, Fort Fisher.

In order to obtain quantitative data on raindrop size and concentration at the time of firing, a method of obtaining permanent records of these quantities was developed.[26] Outing flannel was impregnated with a mixture containing methyl violet. When a square of this material was exposed to rain for a measured length of time, a purple spot was formed for each drop striking the cloth. The diameter of the spot was found to be about 85 per cent of the diam-

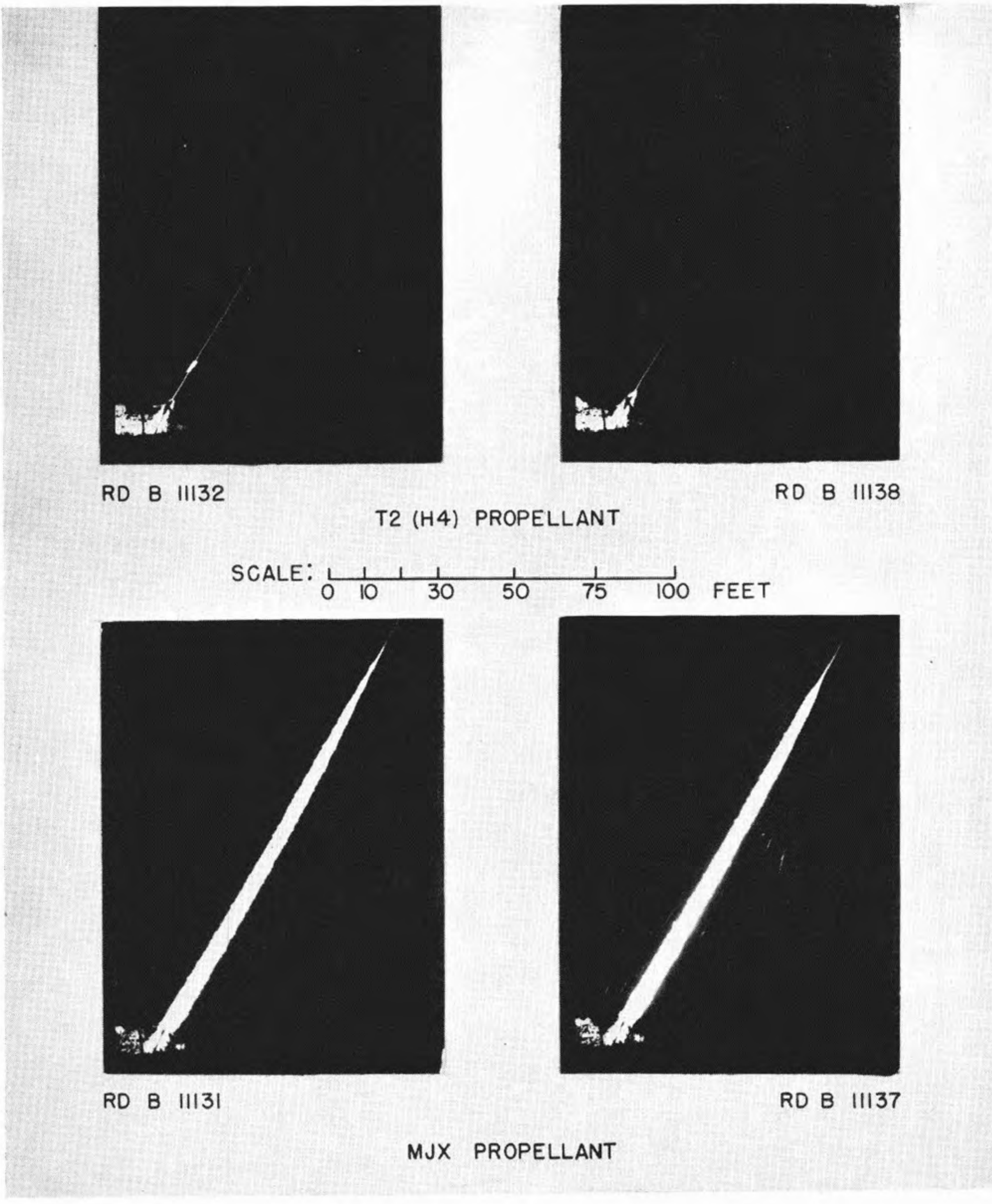


FIGURE 28. Main burning with two propellants, T-83 rocket, Blossom Point.

eter of the drop. From such a record, the number of drops striking unit area in unit time and the diameters of the drops could be determined.

Sympathetic Functioning in Rapid Firing

Tests of fuzed HE-loaded rockets, launched in quick succession, were made to determine whether the fuzes would function sympathetically, that is, whether the ionization or fragments produced by a burst would cause the fuzes on adjacent or succeeding rockets to function also. One fuze in each group of rockets fired in rapid succession was modified to function at a predetermined time. A rotary, multiple-contact firing switch driven by a spring motor was provided to fire the rockets with a desired interval of time, about $\frac{1}{10}$ sec, between successive rockets. Moving pictures and visual observations were made to determine the time and location of bursts.[11]

8.3.9 Investigations of the Exterior Ballistics of Rockets

Introduction

Since the weights and ogives of the rockets as used were seldom standard, the ballistic data required in the course of the development of rocket fuzes were usually obtained at the proving grounds, often simultaneously with tests of fuze performance. Quantities measured were velocity, acceleration, range, angle of terminal approach, rate of spin, and yaw.

The instruments used in these measurements included standard 16-mm moving picture cameras, a Western Electric 16-mm high-speed camera, Hickman 8-mm high-speed cameras, ribbon-frame cameras, still cameras with rotating shutters, ballistic coils, and a photoelectric-radio yaw telemeter. The characteristics of the photographic instruments are given in Chapter 13 of reference 13. Chapter 4 of the same publication describes the mathematical procedures used in trajectory calculations (see also Section 8.4.4).[19, 35, 45, 46]

Velocity, Acceleration, and Range

Velocities were determined photographically if values of velocity in a relatively short portion of the trajectory (several hundred feet or less) were desired; the data were obtained in daylight, using high-speed cameras or ribbon-frame cameras or both. If velocities throughout several thousand feet of trajectory were desired, the rockets were equipped with flame tracers and fired at night. Still 8x10-in. cameras with slotted disk shutters driven by synchronous motors were used to obtain the position of the rockets at known intervals of time. Reference lights were used to establish a scale of distance from the launcher.

None of these methods was capable of giving velocity curves from which reliable acceleration curves could be obtained but did suffice to give average values of acceleration. Atmospheric refraction at night was a particularly troublesome source of error.

In horizontal firing from a tower, a timing disk driven by a synchronous motor and a small mirror through which the launcher could be photographed were placed in the field of the moving picture camera at the side station. From the films so obtained, the average velocity from launcher to target and the velocity at the time of passing the target could be determined whenever desired.

When the ribbon-frame cameras were new, it was found that the synchronous motor drive could be depended upon to give exposures at twice line frequency at voltages greater than 90 v, but after repeated use it was found that the motor drive could no longer be depended upon. The cameras were then equipped with neon-bulb timing devices in which the light from the bulb, which flashes at twice line frequency, was led directly to one edge of the film through a Lucite rod tapered to produce a narrow trace upon the film. At the same time it was determined that velocities obtained photographically and by means of ballistic coils and a cathode-ray chronograph arrangement were in agreement.[25]

Range determinations were made by triangulation from two or more observing stations as described in Section 8.3.6.

Angle of Approach

More reliance was placed upon angles of approach obtained from trajectory calculations

[redacted]

based upon determinations of maximum velocities and ranges at various angles of elevation than upon angles obtained by photographic means. Attempts were made to obtain the angle of approach directly by equipping rockets with tracers and using cameras placed approximately on a line normal to the line of fire at the point of impact, but it was found that atmospheric refraction over water at night introduced errors of such a magnitude that the results could not be trusted.

DETERMINATION OF RATE OF SPIN

Since the rockets used were fin stabilized, spin, when it occurred, was usually accidental and had a speed of not more than several hundred revolutions per minute. Consequently the rate of spin was easily measurable. The rockets used for this purpose were painted half white and half black and photographed in flight with a ribbon-frame camera located off to the side.[17]

By this technique it was found that accidental tilting or bending of the fins of M-9 rockets would produce spin of the rocket. This spin caused malfunction of the arming switch of T-5 and T-6 fuzes (see Section 9.2.2).[21]

MEASUREMENT OF YAW

A few measurements of yaw were made. The frequency of yaw of rockets equipped with smoke tracers and fired from a plane was determined from ordinary 16-mm moving picture film.[8] For one round the frequency and amplitude of yaw were measured during flight by means of a photoelectric-radio telemeter, using the sun as a localized source of light.[10]

8.4 THE FIELD TESTING OF MORTAR SHELL FUZES

8.4.1 Introduction

All mortar shell fuze testing under the auspices of Division 4, NDRC, was performed at Blossom Point (see Section 8.3.1) and at the Clinton Field Station of the University of Iowa. Figure 29 is a graph showing accumulative totals of rounds fired at the two proving grounds.

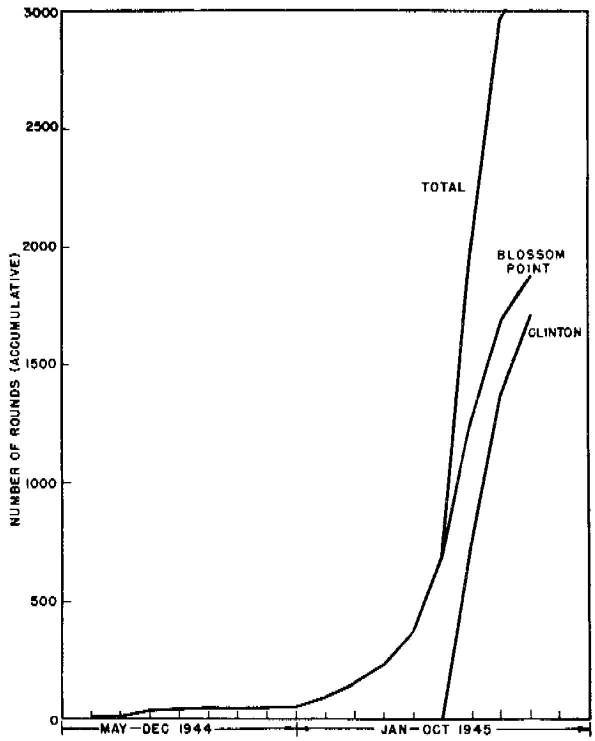
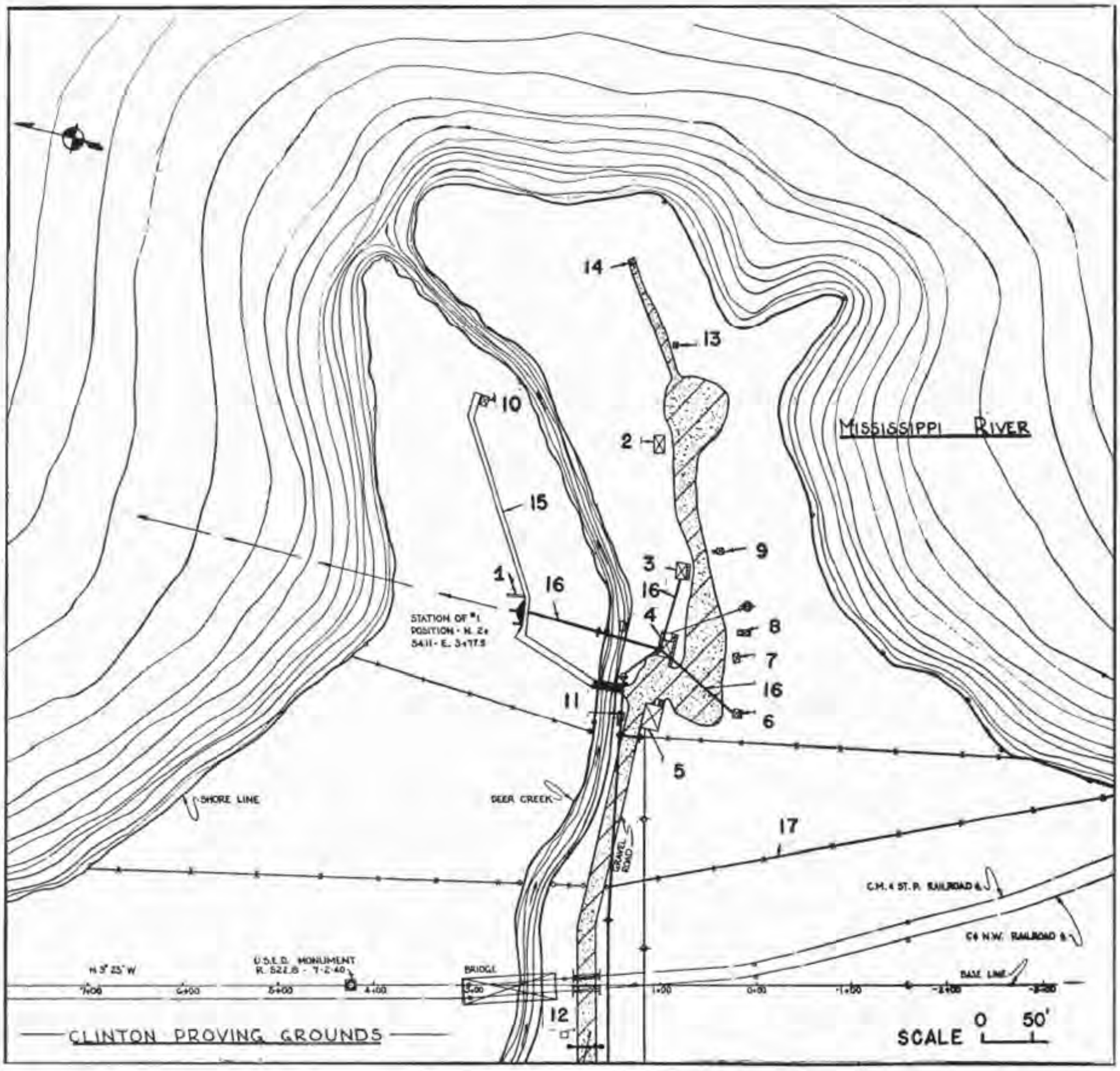


FIGURE 29. Accumulative number of mortar shells fired.

The Clinton Field Station was located along the Mississippi River about 2 miles north of Clinton, Iowa. Figure 30 is a map of the proving ground and Figure 31 a photograph of some of the buildings in the central area. Figure 32 is a photograph of the view down range from Tower No. 1 and Figure 33 is a view of Tower No. 3, which included a fragment-proof shelter.

The testing procedures used at Blossom Point and at Clinton were very similar. The Clinton Field Station was designed exclusively for the purpose of testing mortar shell fuzes. Consequently, the practices obtaining at that proving ground have been considered particularly pertinent in preparing this section of Chapter 8.

One essential difference between the testing of mortar fuzes and other proximity fuzes was in the provisions for taking ballistic data. Range and velocity measurements were taken on most rounds of mortar tests in order to provide data on the effect of the fuze on the flight of the missile.



- ○ Point on line
- ⊖ Telephone pole
- ⊖ Power pole
- ⊗ Base line target
- ✶ Fence
- 1 Gun station
- 2 Storage
- 3 Loading shack
- 4 Radio shack and tower
- 5 Office
- 6 Machine shop
- 7 Equipment room
- 8 Head
- 9 Temporary storage
- 10 High explosive storage
- 11 Guard quarters
- 12 Guard house at front gate
- 13 Detonator storage
- 14 $KMNO_4$ and magnesium puff storage
- 15 Board walk from gun station to No. 10
- 16 Added power lines
- 17 Added fence

FIGURE 30. Map of Clinton Proving Ground.

[redacted]

8.4.2 Personnel and Equipment

Figure 34 shows the distribution of personnel and equipment for a typical test of fuze quality. In addition to the 14 men for whom duties are listed in Figure 34, three were used in loading operations and one for carrying ammunition.

FIGURE 31. View of Clinton Field Station.

The work of developing and reading films, computing and analyzing data, writing reports and handling business details was done in an office building in Clinton, 3 miles from the field station. The personnel in this office included four

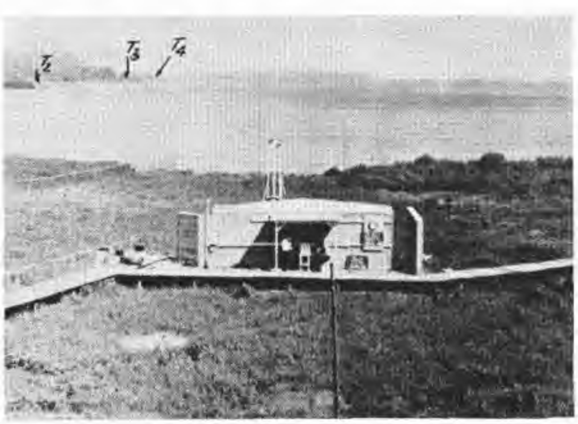


FIGURE 32. View of towers and gun position at Clinton Field Station from T_1 tower.

persons to assemble data and perform calculations, one operator for the film developer, two film readers, two secretaries and two men to analyze data and write reports. A report could be completed in 4 hours after the raw data were received from the field.

8.4.3 Operating Procedures

COORDINATION OF FIRING

It was necessary to set up a definite routine and to exert considerable effort in coordination of the firing operation in order to carry out smoothly a firing program of 100 or more rounds per day. All men were familiarized with the test program before going to their stations and were kept supplied with pertinent informa-

FIGURE 33. View of T_3 tower at Clinton Field Station.

tion during the firing program. The firing operation began with the gunner placing the shell in the release mechanism and asking for clearance from the T_1 tower. The operator in charge at T_1 ascertained clearance and each of the stations informed the gunner of readiness. On the informative count of ten, the gunner caused the release mechanism to drop the shell down the mortar barrel.

Knowing the approximate time of flight of the rounds, it was a simple matter for the

operator in charge to inform everyone when the unit was expected to function. At approximately 2 sec before this time, he gave the signal "camera." The cameras were started on this signal and the aiming circle operators became alert. Much film and time required for reloading the cameras were saved in this manner. If anyone observed an early function or a dud, he immediately informed all operators over the telephone. These methods relieved the operators of undue tenseness and allowed them to be alert at the proper time.

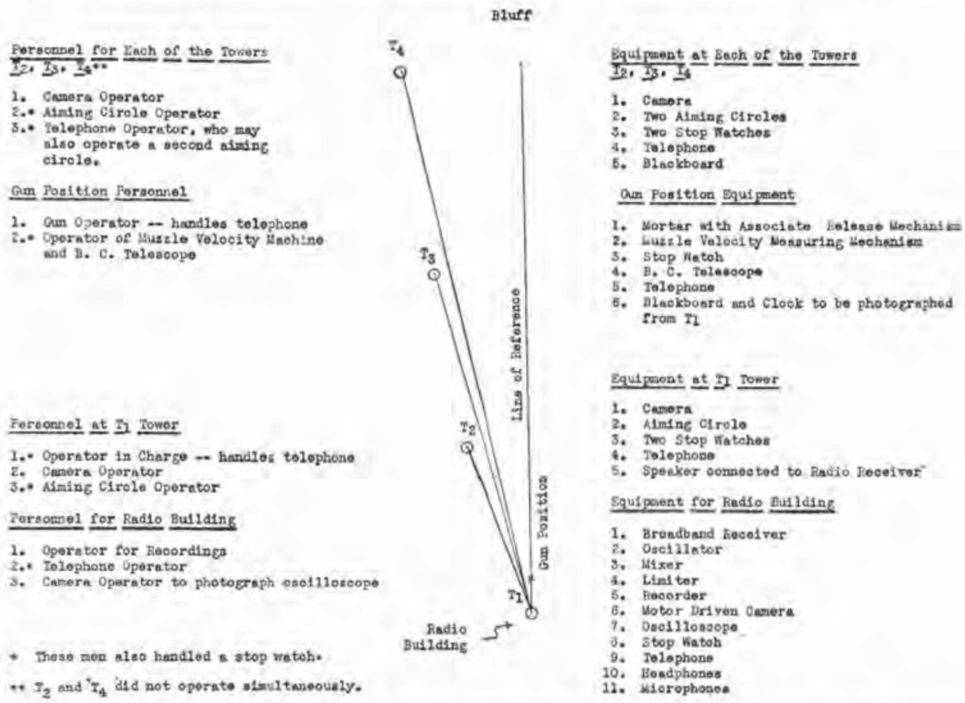


FIGURE 34. Personnel and equipment at observation towers, gun position, and radio building during firing operations.

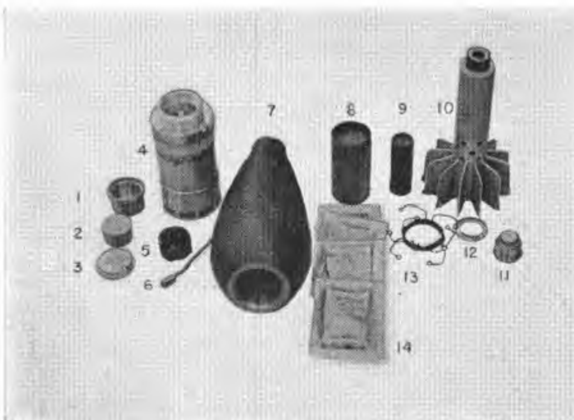
LOADING OPERATIONS

The loading operation involved the assembling of the components (Figure 35) into the complete 81-mm shell with the VT fuze as shown in Figure 36. A supply of the component parts, except the VT fuze, was kept at the field station in order to allow much of the loading operation to be carried out before the day of a firing program. The loading of the detonator into the rotor was the first operation. Figure 37 is a circuit diagram of the device used for testing the rotor after it was loaded. The resistors shown were separate resistors in order to guard against excessive current in case of a short circuit of one of them. Figures 38 and 39 show the fixture into which the rotor was inserted and the testing meter constructed at the field. Identical testing devices were used for the T-132 and T-172 fuzes except that the contacts on the fixtures holding the rotors were different because of the designs of the two rotors. Placing the interrupter plate (also called the lead or tetryl plate) in the fuze and screwing in the booster cup completed the loading of the VT fuze.

Shells as received contained a filler of bismuth carbonate in paraffin wax. To facilitate observation and photography of the height of function, a cartridge containing a mixture of potassium permanganate and magnesium metal was used to provide a flash and smoke puff. A cavity drilled in the shell filler provided a space for this cartridge. The hole for the cartridge was drilled with a 1-in. bit and reamed to a diameter of 1⅛ in. As the program closed, the problem of drilling the filler of stearic acid and plaster paris presented itself. Because this

filler is so much harder than paraffin, it appeared that drilling into it would require the use of a power-operated setup built around a drill press with an unusually long spindle travel.

The M-56 fin was commonly used with the



1 Booster cup
2 Booster pellet
3 Interrupter plate (lead, tetryl)
4 Fuze
5 Fuze rotor
6 Detonator
7 M-43 shell
8 $KMNO_4$-MG puff cartridge
9 Ignition cartridge
10 Fin (tail) for M-56 shell
11 Primer
12 Spacing washer
13 Increment holder
14 Smokeless powder increments

FIGURE 35. Component parts of 81-mm mortar shell with VT fuze.

M-43 shell body. To fit the fin to the body, it was necessary to saw off the first two threads from the fin and insert a spacing washer of $\frac{1}{16}$ in. thick aluminum between the shell and

FIGURE 36. 81-mm shell with VT fuze assembled.

the fin. The shell was then completely assembled with the smoke puff cartridge inserted and the VT fuze screwed into place. After the weight of the shell, the number of the round, and the serial number of the fuze had been recorded, the shell was ready for delivery to the gun position.

GUN POSITION

The mortar was set up (Figure 40) and

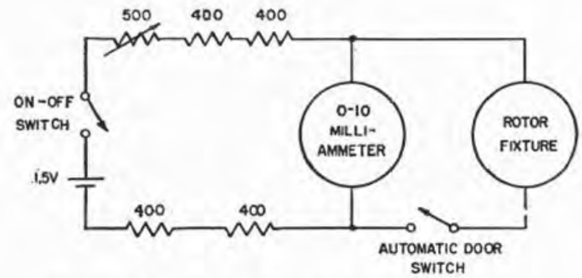


FIGURE 37. Circuit diagram of rotor tester.

aimed in accordance with the instructions given in the Basic Field Manual for this particular gun. Information as to elevation and point of aim were furnished the gunner from

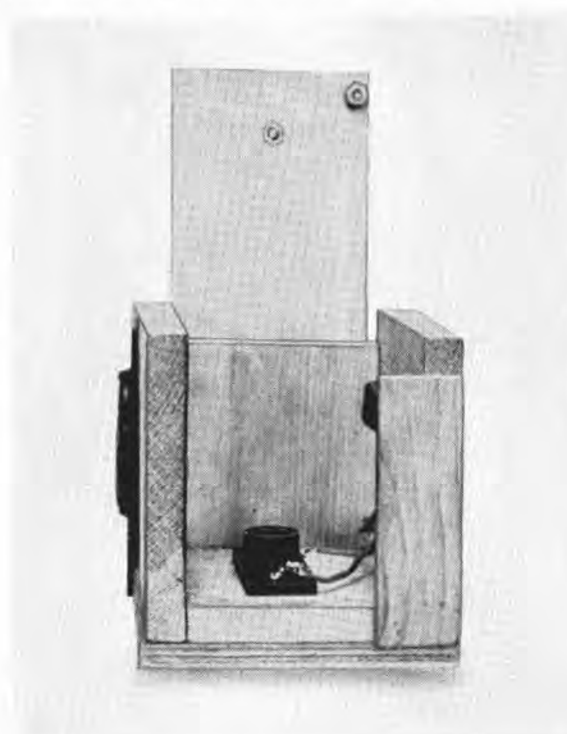


FIGURE 38. Fixture for holding loaded rotor.

the test request and weather data taken prior to firing. The cage on which the solenoid coils (used in muzzle velocity measurements) were mounted was adjusted so that the axes of the

coils coincided with the axis of the gun. The cage was adjusted to the same elevation as the gun (Figure 41) and then shifted in a horizonal plane until the axes coincided.

The person operating the electronic timing

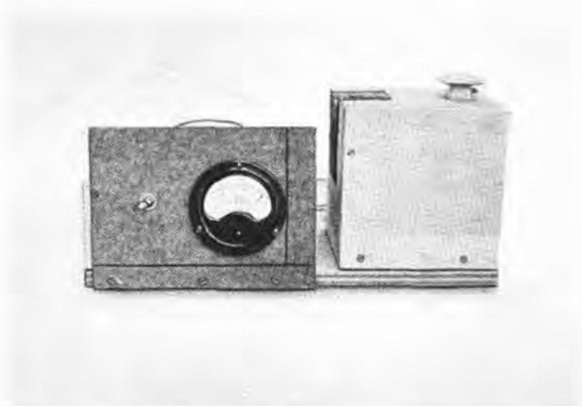


FIGURE 39. Rotor testing meter and jig.

device (Figure 42) for measuring muzzle velocity also operated a battery command [BC] telescope at the gun position. The BC telescope was often used to get a quick check on heights

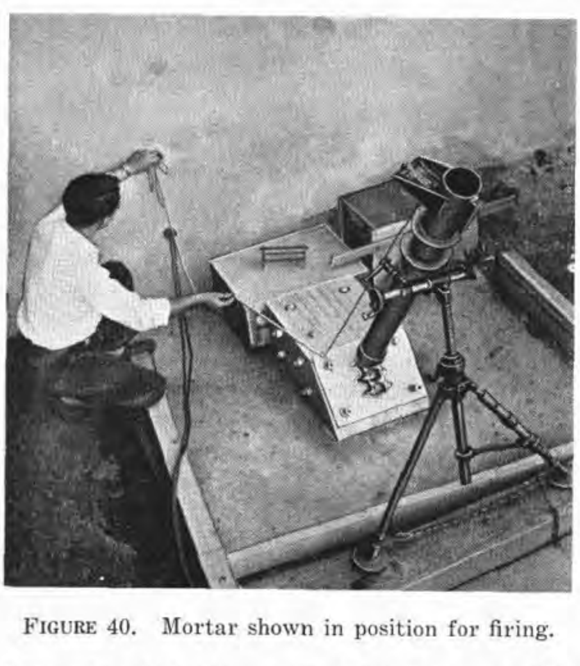


FIGURE 40. Mortar shown in position for firing.

of function. It had a vertical mil scale on which the angle between the smoke puff (or flash) and the splash could be read. From these data and the range, the height of function was readily obtained.

In addition to the apparatus mentioned above,

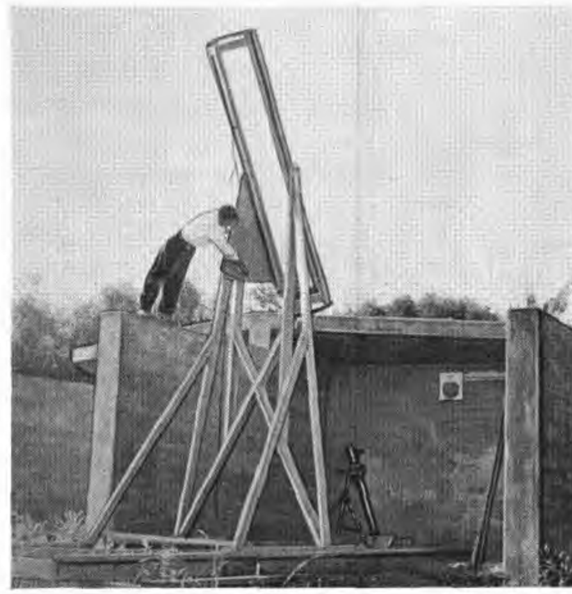


FIGURE 41. Solenoid coils used for measuring muzzle velocity.

a clock and blackboard were located at the gun position (Figure 32) and photographed from T_1 between rounds. The information on the

FIGURE 42. Electronic timing device for measuring muzzle velocity.

blackboard was changed from round to round by the same operator who handled the muzzle velocity apparatus. A detailed description of

the muzzle velocity measuring mechanism is given in reference 41.

Each shell, after inspection, was magnetized so that it would actuate the muzzle velocity apparatus by inserting it in the magnetizing coil (Figure 43). The shell was then placed in

FIGURE 43. Shell being magnetized in magnetization coil.

the special release mechanism (Figure 44) and the mechanism placed on the mortar barrel (Figure 45). This device enabled the operator to drop the shell down the mortar barrel by pulling a string from behind the concrete barricade (see Figures 40 and 42). The gun operator was then ready to ask for clearance from the T_1 tower.

The gun operator was responsible for watching the early flight of the shell so as to note any unusual behavior such as excessive yaw or tumbling. The second operator recorded the muzzle velocity, time of flight of the round, and obtained the mil height of function in the BC telescope. While the gun operator magnetized the next round and placed it in position to be fired, the second operator recorded the firing point data and inserted the serial numbers for the next round on the blackboard.

BALLISTICS DATA

The purpose of this discussion is to explain the method of measurement of the data, the method of calculation of the point of function, and the accuracy to be expected from the

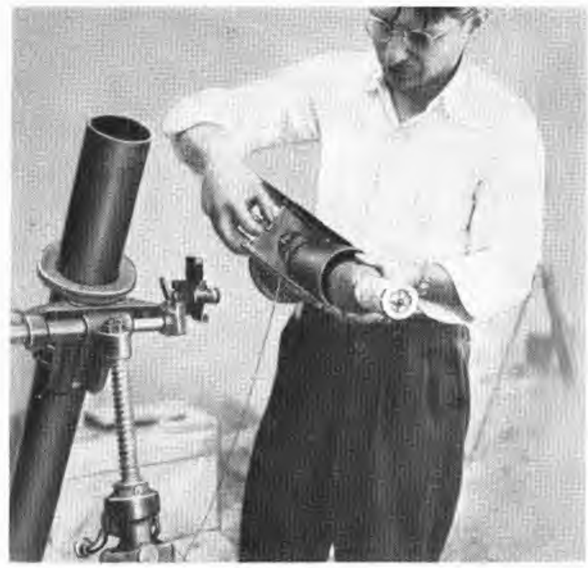


FIGURE 44. Shell being placed in special release mechanism.

methods and apparatus used. It was desirable to know with a fair degree of accuracy the point of function or point of impact of each round. This information was necessary to determine the range and deflection of the round and the height of functioning of the unit. The point of function was located in the event of proper functions; the point of impact in the case of duds. The point of function will be used here to include both cases.

Method of Taking Measurements. Figure 46 shows the location of the four towers, the gun position, and the line of reference. Each of the four towers had at least one aiming circle which was used to measure the azimuth of the point of function. The aiming circle is a device similar to the transit: its calibration is in mils; its field is approximately 85 mils in radius, its magnification 4 to 1; and its turning angle is 360 degrees or 6,400 mils (a mil on the aiming circle is defined as 1/6,400 of a circle). The scale of the aiming circle was in the field of view, the azimuth of the point of function of

the round, with respect to the center of a scale located in the field of view, was read at the time of function. The reading thus obtained was added to or subtracted from the angle of the setting of the aiming circle, depending upon whether the point fell to the right or left of the center line. Since the area of view from the aiming circles was small for points of function near the observation towers, it was at times necessary to employ two overlapping aiming circles in order to locate all of the points of function.

The zero setting of the aiming circle at T_1 tower was along the line from the T_1 to the T_2

FIGURE 45. Shell and release mechanism being placed on mortar barrel.

tower, and the center of the aiming circle was moved clockwise 328 mils to lie along the reference line. The zero settings of the aiming circles at T_2, T_3, and T_4 towers were along the line from these towers to T_1 tower. The azimuth of the point of function of the round was measured from these zero settings in a clockwise direction.

Method of Computation. The following symbols are used in explaining the method of making computations and analyzing the errors involved:

β = angle in mils between line of aim and reference line.

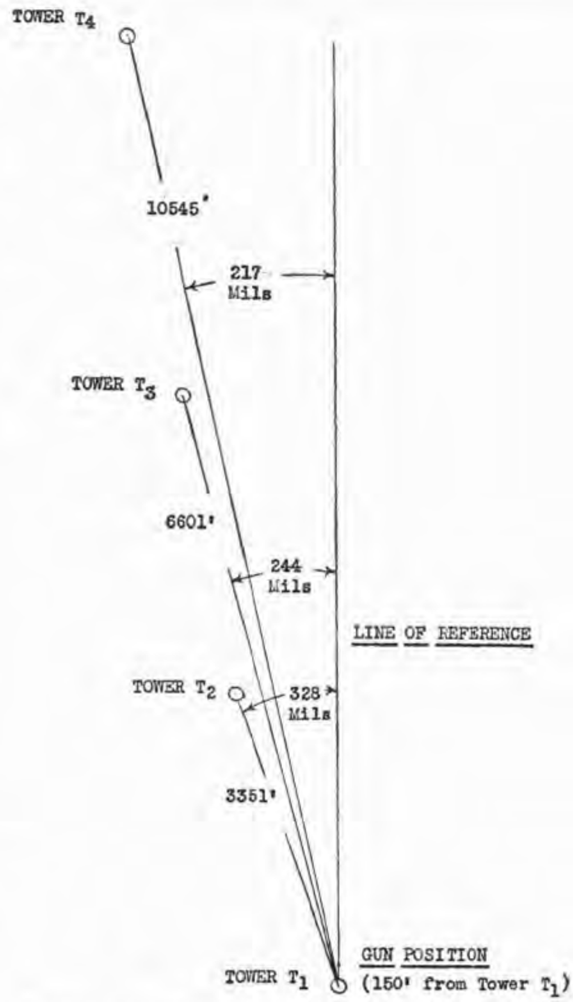


FIGURE 46. Sketch of Clinton Field Station, showing line of reference and position of observation towers and gun.

α = angle in mils measured at T_1 tower from the reference line to the point of function. Both α and β were positive if measured to the right of the reference line and negative if measured to the left.

$T_1 = 328 + \alpha$ in mils, which is the angle between line of T_1 and T_2 towers and point of function.

T_i = angle in mils at T_1 tower measured clockwise from T_1 tower to point of function ($i = 2, 3, 4$).

ΔT_i = indicates the amount of error of measurement, in mils, of the angles T_i ($i = 1, 2, 3, 4$).

[redacted]

[redacted]

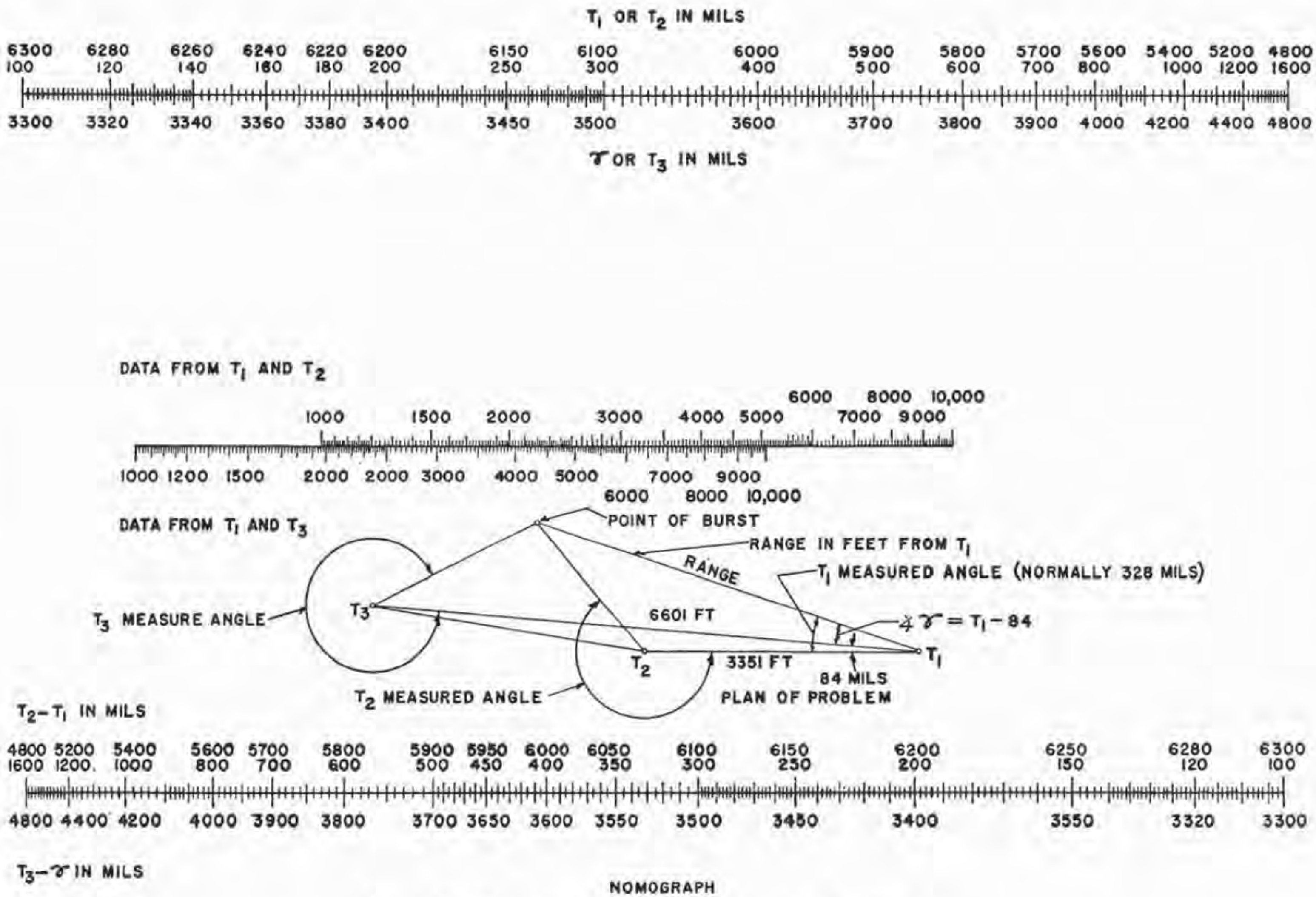


FIGURE 47. Nomograph for rapid determination of range data.

T_1F = the average of two calculations of the distance in feet from T_1 tower to the point of function, in case of discrepancy giving greatest weight to the calculation using the angle measured at the tower nearest to the point of function.

T_1F_i = the distance in feet from T_1 tower to point of function, calculated using angles T_1 and T_i $(i = 2, 3, 4)$.

R = range of the round in feet, i.e., the distance from gun position to point of function.

T_iF_1 = the distance in feet from T_i tower to point of function of the round, calculated using the angles measured at T_1 and T_i towers $(i = 2, 3, 4)$.

Knowing the angles T_1 and T_i $(i = 2, 3, \text{or } 4)$ and the distance from T_1 to T_i, the distance from T_1 to the point of function of the round was calculated by use of the law of sines. Since the angle T_2 and T_3, or angles T_3 and T_4 were always obtained, there were two calculations for each point of function to check against each other. Similarly, T_2F_1, T_3F_1, T_4F_1 were calculated by use of the law of sines.

A nomograph was constructed to solve the trigonometric relations between the above terms. Figure 47 exhibits the nomograph used. The final distance T_1F was given as the average of T_1F_2 and T_1F_3 or of T_1F_3 and T_1F_4, giving greatest weight to the value calculated with the data from the tower nearest the point of function.

The range R of the round in feet was then calculated from the following equation:

$$R = T_1F - 150,$$

where 150 was the distance in feet from the T_1 tower to the gun position, and lay along the line of reference.

The deflection D of the round in feet was the perpendicular distance from the point of function to the line of aim. This distance in feet was given by the approximate formula:

$$D = T_1F\ (\alpha - \beta).$$

Errors to Be Expected. There were several factors affecting the accuracy of measurement of the point of function. The influence of these on the range of the shell is discussed below.

1. Errors in measurements of the locations of the various towers. These points were surveyed by a professional surveyor, and the measurements were checked carefully. It was felt that errors from this source were negligible.

2. Errors in measurement of angles at the various towers. These angles could be measured with an error of ± 1 mil. Figure 48 shows

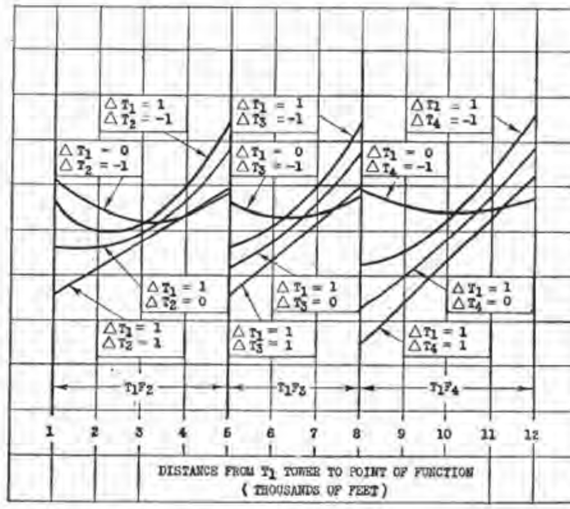


FIGURE 48. Graph showing errors in computed distance from T_1 tower to point of function for errors of 1 mil in angles measured at various observation towers.

graphs of the errors in T_1F_2, T_1F_3, and T_1F_4 to be expected when errors of 1 mil were made in measuring the various angles. Inspection of these graphs shows that by using the data from the proper towers, the maximum error in the distance from T_1 tower to the point of function for ranges from 1,000 to 12,000 ft is 13 ft.

3. There was also an error in subtracting 150 ft from the distance T_1F in order to get the range of the round, unless the point of function fell along the line of reference. This error is equal to $150 \times \sin \alpha$. Since α is a small angle, the error from this source is insignificant.

4. The size of the nomograph constructed to solve the equations was 24x36 in. Calculations using this nomograph should be more accurate than calculations using the conventional 10-in. slide rule. Calculations showed that the nomo-

graph could be read with an error of less than 5 ft.

5. The method of calculating the deflection was approximate, since the assumption was that the sine of the angle $(\alpha - \beta)$ equaled the angle. This was nearly true, since the angle was small. Errors in measuring the angles α and β would also result in an error in calculating the deflection. Using an estimated measurement accuracy of 1 mil, the maximum error in the angle $(\alpha - \beta)$ would be 2 mils. This would result in a maximum error of approximately 2 ft per thousand feet of range.

FIGURE 49. Houston film developer, Model 11, Type K-3 in use.

METHOD OF OBTAINING HEIGHTS OF FUNCTION

The height of function of the VT fuze was determined by measuring the enlarged image of a 16-mm motion picture film. Pictures were taken from three positions: one behind the firing point and two along the line of flight of the shell. Bell and Howell Filmo Cameras, Model 70-DA, were used, operating at maximum speed of 64 frames per second. The camera at the T_1 tower pointed along the flight line and was equipped with a 4-in. telephoto lens. At the other two stations a 2-in. lens was used unless the camera was pointed at a small enough angle to the flight line to insure the function being in a small field of view, in which case a 4-in. lens was used. The cameras were also equipped with 1-in. lenses for photographing (after each function) a blackboard giving the round and fuze number. The operators started the cameras for photographing functions when the signal "camera" was given by the operator in charge. This signal was given approximately 2 sec before the estimated functioning time.

The film was processed with a Houston Film Developer, Model 11, Type K-3. Best results were obtained by following the procedure in reference 48. Ansco Hypan film was used. Figure 49 shows the film being processed in the Houston Developer.

The Recordak Film Reader, Model C, was used to obtain an enlarged image of the finished film. The image was measured to the nearest 0.02 in. Magnification of the image was carefully checked by measuring the height of known objects at known distances. Since the focal length of the lens and the distance from camera to function were known, the height of function was computed, using the formula,

$$\text{Height of function} = \frac{\text{Measured height of image} \times \text{distance to function}}{\text{Focal length} \times K},$$

where K is the magnification of the image. This formula is accurate to 1 ft at a range of 4,400 ft. There was always at least one camera station within this range. Hence the accuracy was consistently within a foot of the height of function if the picture showed the actual height of function.

FUZE FLIGHT PERFORMANCE

A block diagram of the radio equipment is shown in Figure 50.

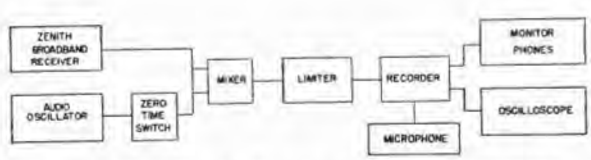


FIGURE 50. Block diagram of radio apparatus.

A Zenith broad band receiver with a flat frequency response of ± 3 mc was used. Two dipole antennas were connected by 50-ohm transmission lines to the receiver. One antenna was used for the Globe-Union units, the other for Zenith units. A Hewlett-Packard Model

200C audio oscillator supplied the 1,000-c note used to obtain zero time. This 1,000-c note was shut off at the gun position by a switch actuated by muzzle blast from the gun. A mixer amplifier fed both the 1,000-c note and the signal from the receiver into the network at the same time. This unit had very little gain and was used primarily for mixing. A limiter, designed to keep the signal at a constant level, was coupled as shown to the Presto 8-K recorder. A microphone connected into the recorder circuit made possible the recording of voice announcements associated with the firing of each round. All recordings were made with a sapphire cutting needle on Audiodisks. Before firing a given round, the receiver was tuned to the expected frequency of the unit listed on the test request data sheet.

Coordinating the radio with the firing operation was carried out as follows. As the gun operator began counting, the man at the telephone in the radio laboratory counted aloud in unison with him. This gave the other operator time to start recording the 1,000-c note. As the shot was fired, the note was cut off sharply by the micro switch and the signal from the unit cut in. The termination of the 1,000-c note gave the zero time for the signal being recorded. A check was kept on the relative strength of the signal by observing the monitoring meter on the recorder, designating the optimum signal strength by the number 5. The volume of the 1,000-c note was always set to 4. The quality of the signal was determined by ear, again designating by 5 the optimum quality. Both readings were recorded on a data sheet for each round. The radio operator timed the duration of the signal with a stopwatch and at the end of each signal recorded the round number on the disk.

Determination of Generator Speed. To record generator frequency, the signal received from the fuze was fed to the horizontal plates of an oscilloscope. The vertical plates were tied together and grounded. Best results were obtained by picking up the signal from the monitor of the recorder. The oscilloscope was then photographed with a Bell and Howell, Model 70-DA, 16-mm motion picture camera from which the shutter mechanism had been removed and the spring drive replaced by a synchronous motor giving a film speed of 15 in. per sec. The camera and oscilloscope were enclosed in a dark chamber.

Approximately a second before the shell was fired, the camera was started. The 1,000-c note from the audio oscillator was recorded until the firing of the mortar operated the zero time device. The generator frequency was recorded on the film from this time until the functioning of the fuze.

Ansco Triple S Pan and Eastman Super XX films were found to be the most easily read. After processing, the films were marked at 15 in. intervals in order that readings could be taken every second. Readings were also taken at three points in the first second, since the speed changed rapidly immediately after the shell was fired. Reading of the films was done on the Recordak Film Reader, Model C. Since the generator had six poles, the generator speed equals $\frac{1}{3}$ of the frequency.

Although the equipment operated well, the system was not completely satisfactory. The 1,000-c note was used as a standard to check the apparatus and results were consistently very good. However, the carrier from the fuze was modulated by the plate voltage ripple and also by the filament voltage. The filament modulation gave the fundamental frequency and the plate voltage ripple gave the first harmonic. During the flight of the shell, the predominate modulation was first the filament voltage, then the plate voltage ripple, and finally the filament voltage again at the end of the trajectory. Hence, extreme care had to be taken to avoid confusing the fundamentals with the harmonic. Reporter units should have been used when accurate generator speeds were needed.

Carrier modulation was also recorded on phonograph records which were analyzed by a method described in the Bibliography.[13]

Weather Data

The purpose of collecting weather data was to obtain information pertinent to ballistic calculations and also to determine any adverse effects of weather on the VT fuze.

The direction and velocity of the surface wind were determined, respectively, by a wind

[redacted]

vane and an anemometer. To determine wind at higher altitudes, a pilot balloon was released each hour during firing and theodolite readings taken on the position of the balloon. Reference 47 was used to convert these readings to an average wind for each 1,000-ft zone. A ballistic wind was then calculated by averaging these zone winds weighted as to the time the projectile was in each zone. Although no attempt had been made to correct the ballistic data for wind, the recorded ballistic wind could have been used for this purpose.

The sky condition was recorded as overcast, broken, scattered, or clear, depending on whether the coverage of the sky was over 0.9, between 0.5 and 0.9, between 0.1 and 0.5, or less than 0.1, respectively. Standard weather bureau terminology was used to describe cloud types.

Continuous daily recording of temperature, atmospheric pressure, and humidity were made by thermograph, barograph, and hydrograph, respectively. Other pertinent weather information, such as fog and precipitation, were also recorded.

Field Test Reports

Immediately after a firing program was completed or at intervals during long programs, data from the field were brought into the office in Clinton and given to the computing group. These raw data were then transcribed into a calculation sheet.

Rounds fired were numbered consecutively, and these round numbers were used to coordinate all data. Data sheets were furnished to the loading department, the gun station, radio operators, and tower observers for recording such information as the type of vehicle and fuze, weight of complete round, charge, angle of elevation, type of function, time of function, azimuth of function, strength and quality of radio signal, and muzzle velocity. Specially prepared forms were used to record the data at the field.

A calculation sheet was made up to be used with the nomograph described in the discussion of ballistic data given in this section. On this sheet, the columns were arranged to allow orderly recording of the data for rapid computation.

When the calculations were completed, they were recorded on a field test report sheet. This sheet contained the results of the test in a compact form and included the principal data submitted in the Field Test Reports. As used in this report, the mean dispersion of a group of variables was defined as the average of absolute values of the differences between the mean value of the variables and the particular variables.

The request for field tests included the following information: (1) originator of the test; (2) the contact person representing the originator; (3) purpose of test; (4) description and conditions of test; (5) description of material to be tested; (6) data required from the test; (7) source of material; (8) urgency of test; (9) relation of other test requests; (10) statement as to whether originator's representative would witness the test; (11) remarks; (12) approval of test request by originator; (13) approval or modification of test request by the director of the field station.

Immediately upon receipt of a test request, one person was assigned to study the test request and begin writing as much of the report as was possible before the data were obtained from the field station. This was necessary in order to facilitate sending reports out on the day the firing was done.

8.4.4 The Mathematical Calculation of Mortar Shell Trajectories

Three methods for the computation of mortar shell trajectories[45] were considered, namely, the Piton-Bressant procedure, a method especially adapted to the use of the quadratic air-resistance law, and the method of numerical integration as developed in 1918 and the following few years. It was found that existing ballistic tables were inapplicable to the particular type of mortar shell in question, since the tables give trajectories only for shells whose ballistic coefficients are greater than or equal to unity while these mortar shells have ballistic coefficients of one-half or less.

The Piton-Bressant method requires a knowledge of the initial conditions, that is,

[redacted]

muzzle velocity and elevation of the mortar, and of the range on the horizontal. This method is the easiest of the three to apply, but it is subject to an inherent error of a magnitude indicated by Figure 51. No particular assumption is made about air resistance, the effect of which is taken into account by the use made of the measured range. The method permits the calculation of as many points on the trajectory as may be desired, together with the time at each.

In the second method, it is assumed that the

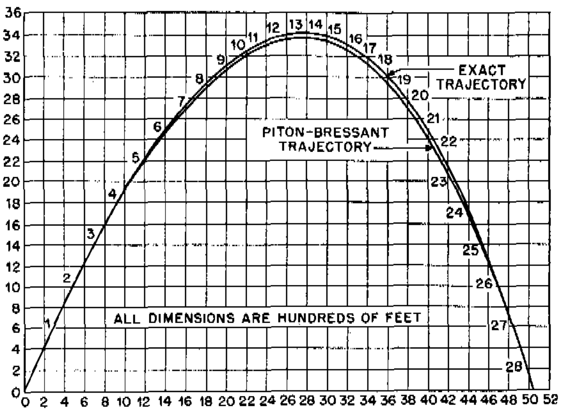


FIGURE 51. Comparison of trajectory calculated by Piton-Bressant procedure with exact trajectory.

drag of the air is given by the expression cv^2, where v is the velocity of the shell at any time and c is a constant whose value must be found from field or wind tunnel measurements. Formulas were developed giving the coordinates and time as functions of the inclination. By means of these formulas, as many points on the trajectory can be calculated as may be desired, together with the time at each. This method is capable of as much accuracy as the measured data warrant. It was this method which was used in calculating the "exact trajectory" of the figure.

Since the type of mortar shell under consideration has a ballistic coefficient less than unity (corresponding to a relatively large air resistance), the effect caused by the decrease in air density with increasing height may be appreciable on the trajectory as a whole. In order to test this point the trajectory for a muzzle velocity of 635 fps, an elevation of the mortar of 65 degrees, and a ballistic coefficient of 0.4284[b] was calculated by the method of numerical integration using the tabulated Gavre function first with account taken of the change in air density with changing altitude and then ignoring this change. The respective ranges were found to be 5,033 and 4,901 ft. The difference is 132 ft, or about 2.6 per cent of the range.

Formulas were developed for the effects produced by small changes in initial conditions. The method of differentials was used in this connection. Application of these formulas was made to the problem of the effect of wind on a trajectory.[46]

8.4.5 Photographing Height of Function of VT Fuze

INTRODUCTION

Experiments were performed for the purpose of gaining more definite information on the measurements of heights of function of the VT fuze. The heights of function were calculated from photographic data taken at three observation towers. To obtain the actual height at which the VT fuze functioned, it was desirable to photograph the detonation of the tetryl in the fuze; this was the first indication of the functioning of the fuze. During a certain period, when potassium permanganate and magnesium packs were not available to be placed behind the tetryl pellet to make a puff after the fuze functioned, black powder was employed for this purpose. The functioning of approximately two hundred of the fuzes was photographed at this time by three cameras operating at 64 frames per second, and in no instance did a flash appear on any of the films. Three fuzes were then placed in the mortar shells in the usual manner, except that the black powder was missing, and were statically detonated. Again, a flash was not recorded on any one of the films. Hence, it was assumed that when potassium permanganate and magnesium puffs were used, the flash appearing on the film was actually from the potassium permanganate

[b] Approximately the value for the M-43C shell with the T-132 fuze.

[redacted]

and magnesium and not from the tetryl pellet. Potassium permanganate and magnesium was used thereafter for making the puff, and a flash appeared on the film for each proper function.

The disagreement between the heights of function obtained from the photographs from the three towers was greater than 1 ft in only 3 per cent of the cases and was never greater than 2 ft. Thus, the method of measuring the heights of the puffs seemed to be quite accurate.

Experiments to Determine Whether Actual Heights of Function Were Being Photographed

Experiment I. The first evidence of function should be the detonation of the tetryl booster pellet. To discover if this detonation was capable of being photographed, 10 tetryl booster pellets were statically detonated by taping each pellet to an electric detonator and fired by means of a hand magneto. Motion pictures taken at 64 frames per sec showed a definite flash. The explosions were also photographed by a shutterless motor-driven camera. Measurement of the length of a bright streak on the finished film from this camera showed the duration of flash to be 0.02 sec.

Experiment II. Three M-43 inert loaded shells were loaded with detonator and tetryl booster pellet only. The tetryl was held in the aluminum tetryl cup in a standard M-53 PD fuze. These units were detonated statically as in experiment I and photographed with three cameras operating simultaneously. Photographic data showed a brilliant flash with an average duration of 0.18 sec. The flash was followed by a thin gray smoke.

Experiment III. Three M-43 inert loaded shells were packed with detonator and tetryl pellet. The tetryl was held in a brass tetryl cup in a reject VT fuze. The units were statically detonated and photographed with three cameras. There was no evidence of a flash on the finished film. A dense black smoke was the first visible record of function. This possibly indicated that the flash seen in using tetryl packed in aluminum cups may have come from the burning aluminum. The flash seen in the case of tetryl alone was not present when the tetryl was packed in brass, possibly because the energy from the detonation was used in breaking and heating the shell.

Experiment IV. Eighteen units were loaded as in experiment III and fired from the standard 81-mm M-1 mortar. There was no evidence of a flash when the functioning of these units was photographed by three cameras. However, smoke was plainly visible on the films.

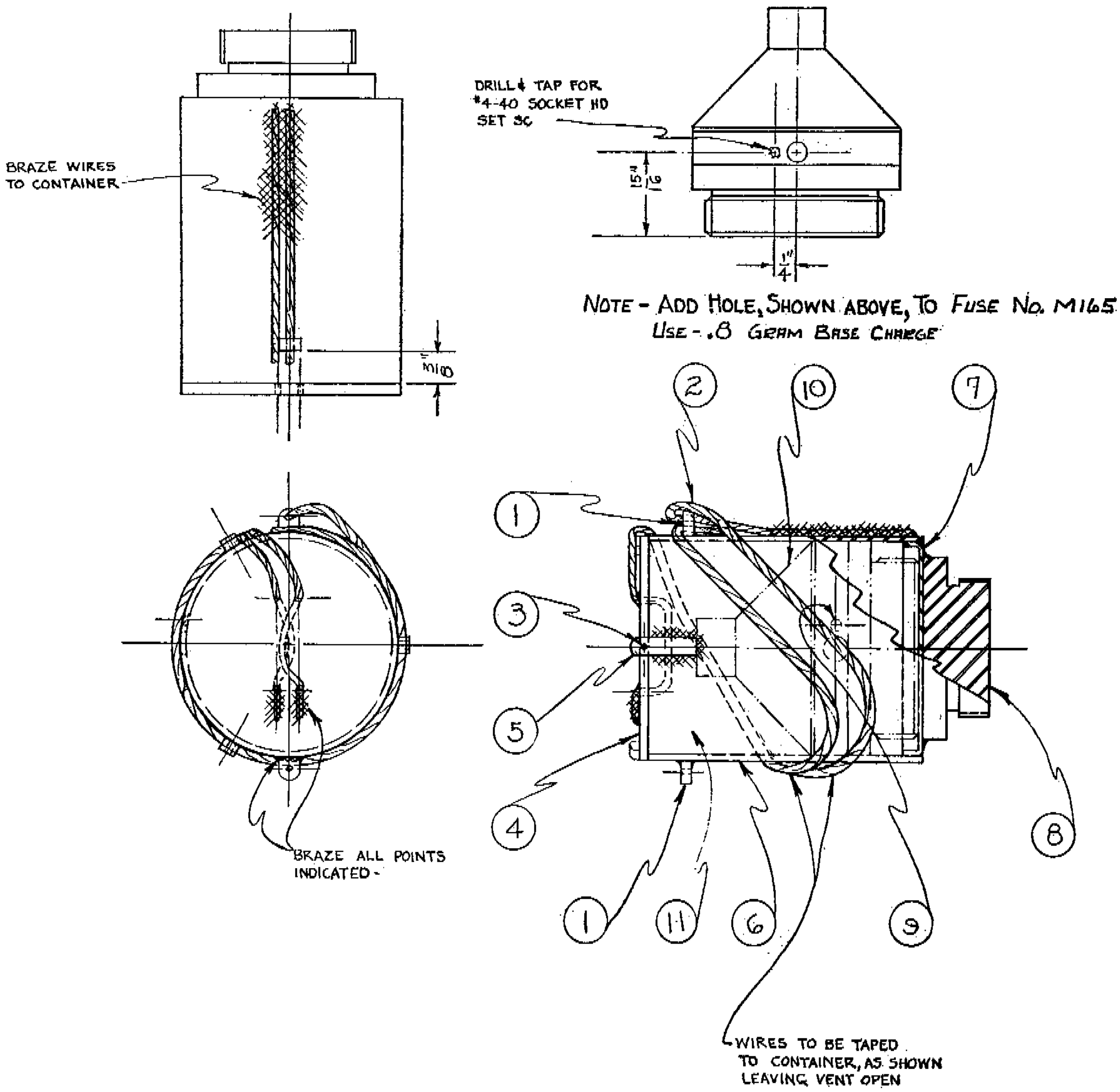
Experiment V. Units loaded with a black powder cartridge behind the tetryl cup showed smoke as the first visible evidence of function. In photographs of 200 units packed with the black powder cartridge, there was no record of a flash.

Experiment VI. Shells were ordinarily packed with a cartridge of potassium permanganate and magnesium behind the booster pellet. The functioning of this round photographed nicely as a black point topped or surrounded by a flash. The flash was found to photograph well against a water background in all types of weather. Considering the above experiments, the conclusion is drawn that this flash was caused by the potassium permanganate and magnesium and not by the tetryl pellet. A complete account of the preceding experiments together with photographs may be found in reference 43. Comparisons of black powder and permanganate-magnesium spotting charges are also reported in reference 23.

Comparison of Heights of Function Obtained from Three Observation Towers

The shutter on the cameras used in photographing the functioning of the VT fuze had an opening of 204 degrees. When operating at 64 frames per sec, the shutter was open 0.0088 sec and then closed 0.0068 sec. Hence, the shutter was open approximately $5/9$ of the time and closed $4/9$ of the time. With three cameras operating essentially independently of one another, the probability of missing the first evidence of function was $(4/9)^3$, or approximately $1/11$. If the shell had a maximum approach velocity of 500 fps, it might have traveled as much as 3.4 ft while the shutter on one of the cameras was closed. Since agreement among three camera stations was consistently within a foot, it seems

unlikely that the explosion was carried downward with the same velocity as the shell. Any error larger than a foot between readings was invariably the result of faulty measuring or computing.

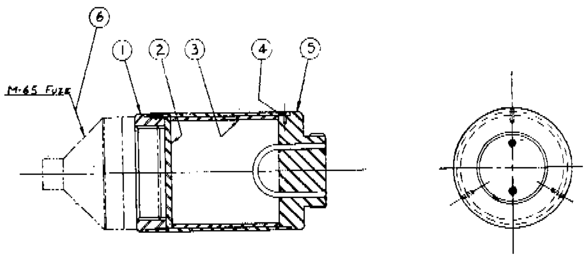


1. Cable guide
2. Steel cable
3. Shear pin
4. Cover
5. Stud for shear pin
6. Steel tube
7. Base plate
8. Threaded base
9. Set screw
10. Time fuze
11. Parachute space

FIGURE 52. Type A-1 mortar shell retrieving device.

Measurements were taken from the highest point from which the explosion appeared to emanate to the water below the functioning point. Since the cameras were operating independently, the detonation might have taken place while one or more of the camera shutters were closed. However, the close agreement of data from the three cameras indicated that the point of function remained fixed and visible for a sufficient length of time to be recorded photographically in all three cases.

Furthermore, this close agreement seemed to substantiate the fact that the results were accurate. The only error present may have been the result of the time lapse between the functioning of the fuze and the appearance of visible evidence of it. Considering the fact that tetryl has



Note- Use One Gram Base Charge

1. Adapter for M-65 fuze
2. Steel plate
3. Internal steel tube (half cylinders)
4. Shear pin
5. Threaded base
6. Time fuze

FIGURE 53. Type A-2 mortar shell retrieving device.

a rate of detonation of thousands of meters per second, the error introduced was less than 1 ft.

8.4.6 Parachute Recovery Devices

INTRODUCTION

During the development of the VT mortar fuzes, it became apparent that some means was needed to allow the fuzes to be subjected to

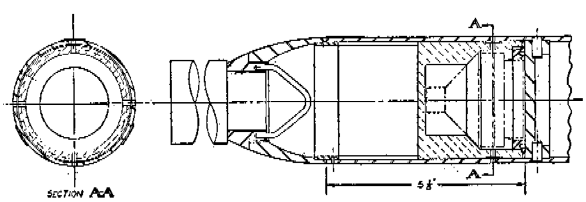


FIGURE 54. Type B fuze retrieving unit.

accelerations comparable with the accelerations encountered in actual firing and still permit further testing and inspection of these fuzes. This was necessary so that damage to the fuze caused by acceleration might be studied and faulty or failing parts redesigned. The centrifuge furnished a partial solution to the problem. However, the accelerations available with the centrifuge did not accurately simulate the instantaneous acceleration encountered in actual firing. It was agreed that some means for recovery of fuzes after they had actually been fired and gone through part of a normal flight was needed. The development of a recovery device was assigned to the University of Iowa.

Devices for parachute recovery not only of the VT fuzes but of complete 81-mm mortar shells were developed and put into production and use. On the whole, these devices functioned satisfactorily. The various types of devices, their applications and use will be discussed below.[44]

TYPE A-1 DEVICE

The first device developed consisted of a tubular steel parachute container with threaded base. The threaded base was screwed into the mortar shell in the position normally occupied by the shell fuze. This device was intended for recovery of the complete projectile. A fuze or other material of interest could be mounted inside the shell body. The original design (type A) proved unsatisfactory and was never used.

Figure 52 is a drawing of the type A-1 device as used. Space was provided for a fixed time (15 sec) powder train fuze (M-65) to eject the parachute. The M-65 fuze was inserted in the bottom of the container and the parachute was packed snugly against the fuze. The cover was placed over the parachute and held in position by three 0.081-in. half-hard brass shear pins. The cover was fastened securely to the container through two $\frac{1}{8}$-in. flexible steel cables. One end of each cable was brazed to the outside of the container. The other end of each cable was passed down through the top of the cover and back up through the cover from the bottom. The ends were then brazed to the top of the cover. A loop in the steel cables for attachment of the parachute shroud lines was left on the bottom side of the cover.

In operation, the M-65 fuze was initiated when the shell was fired. After 15 sec of flight, the powder train ignited a reduced (approximately 1 g) charge of black powder in the base of the fuze and forced the fuze forward; this sheared the pins retaining the cover and forced

the parachute out. The whole shell was then recovered on the parachute.

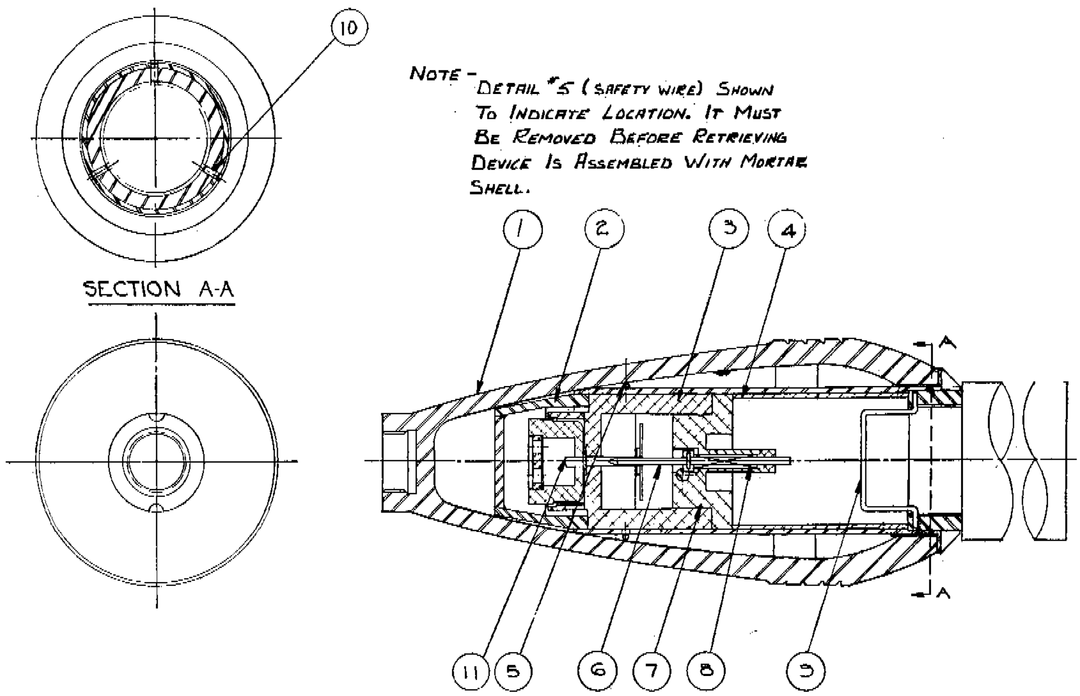
The principal difficulty encountered in the use of this device was separation of the steel cables from the container at the point where they were brazed. This difficulty was practically eliminated by greater care not to overheat the cables in brazing. At the Clinton Field Station, 80 of these devices were used to recover complete rounds of M-56 mortar shells. Of the 80 used, 61 functioned satisfactorily.

Type A-2 Device

The type A-2 device was never built, though drawings were prepared. It provided for secure fastening of the parachute shroud lines to the threaded base and eliminated the steel cables used on the type A-1 device. Approximately the same size and shape container was used as for the type A-1 device. Provision was made for mounting the M-65 fuze to operate the device on the extreme front end of the assembly. The base charge of the M-65 fuze was used to shear half-hard brass pins and release the parachute. Figure 53 is a drawing of the type A-2 device.

Type B Device

The type B device was developed very soon after the type A device and was actually in production first. It was built into a modified M-56 mortar shell. This device provided for mounting the VT fuze in its normal position on the shell.



1. Mortar shell
2. Steel housing
3. Part from M-111 or M-111 A-2 time fuze
4. Steel tube (half cylinders)
5. Safety wire
6. Part from M-111 or M-111 A-2 time fuze
7. Part from M-111 or M-111 A-2 time fuze
8. Part from M-111 or M-111 A-2 time fuze
9. Loop anchor for shroud lines
10. Shear pin
11. Primer

FIGURE 55. Type C fuze retrieving device.

The M-56 mortar shell was modified as follows. The nose of the shell was cut off just forward of the three small bosses which touch the barrel (actually right at the line between the shell nose and the straight part of body). The inside of the shell body was reamed to a standard size. A circular steel plate was pressed

[redacted]

down inside the shell to a depth of approximately 6 in. and secured by steel pins pressed through the shell wall and into the plate. The space forward of this steel plate was used for the parachute and an aluminum piston in which an M-65 powder train fuze was mounted. The nose was fastened back on the shell body with a short piece of steel tube pressed inside the nose and held to the body with 3 half-hard brass pins (0.081 in. in diameter). A loop of steel rod brazed to the nose served as an anchor point for the parachute shroud lines. The completed device presented the same external appearance as a standard M-56 shell. Figure 54 is a drawing of the type B device.

When the shell was fired, the M-65 powder train fuze was initiated and the time ring began burning. After 15 sec of flight, the time ring ignited the base charge (reduced to 1 g) of black powder in the fuze. This forced the nose off and expelled the parachute. The nose with the VT fuze attached was brought down on the parachute.

At the Clinton Field Station 45 of these devices were used. Of the 45 tried, 44 functioned satisfactorily. Several hundred of these devices were shipped to Blossom Point, where they also functioned satisfactorily.

All of the parachutes for types A, A-1, A-2, and B devices were 36-in. Fortesan rayon canopies with 100-lb rayon shroud lines. Some of the canopies were white and some were dyed orange to make them easier to follow.

Type C Device

One objection to the type B device was that it was built into an M-56 mortar shell; consequently, it was impossible to subject the VT fuze to the accelerations desired. The design was such that it could not be adapted to the lighter M-43 shell with which the higher accelerations might be realized. Therefore, development was begun on a completely new device which would work equally well in the M-56 or M-43 mortar shell. This device, designated as type C, was still in the development stage when operations were terminated. The type C device was a complete unit which might be inserted in either an M-56 or M-43 A-1 empty shell after removal of the adapter ring in the shell nose. It provided for mounting the VT fuze in its normal position. After the type C device was inserted in either the M-56 or M-43 A-1 mortar shell, the shell presented approximately the same external appearance as before. The device was built into a steel tube approximately 6 in. long and $1\frac{3}{4}$-in. inside diameter. Space was provided for an adjustable time mechanical time fuze, a parachute, and a nose ring with threads for the VT fuze. The time fuze used was actually part of two standard fuzes, the M-111 or M-111 A-2, and the M-136. The timing elements or clocks in these two fuzes were identical in external appearance and differed only in the rate at which the timing disk turned. The body of the M-111 fuze and the clock from the M-136 fuze were used. The hybrid fuze thus made up was modified so that it was acceleration initiated instead of arming wire initiated as originally. The delayed arming mechanism was removed completely. The parachute used was a 30-in. Bemberg rayon canopy with 40-lb rayon shroud lines. Figure 55 is a drawing of the type C device.

In operation the time fuze was initiated when the shell was fired, and the base charge was ignited at any desired time thereafter (time was adjustable from 5 to 30 sec). This forced the time fuze forward, pushed the nose ring off and expelled the parachute. The nose ring and the VT fuze were recovered on the parachute.

At Clinton Field Station, 15 units were tested. Of the 15 tested, five functioned satisfactorily.

Recovery Procedure

In practice, rounds fired for recovery were fired at an elevation of 75 to 80 degrees so that the shell would be traveling slowly when the parachute opened. Actual recovery of shells or fuzes was somewhat complicated by the fact that firing was done over water and recovery was by boat.

Ordinarily two boats were sent out. They stood by out of the line of fire until after the parachute opened. Usually the men in the boats could see the parachute open and get into position to pick it up very soon after it hit the water. When the men in the boat did not see the

parachute, flag signals from shore were used to direct the boats toward the point where the parachute was expected to fall.

Usually the parachute hit in such a manner as to trap air between the water and the canopy and remained afloat for several minutes. If the parachute sank, aiming circle bearings from two towers (T_1 and T_2) were taken on the point where parachutes sank. Use was made of these data to recover several shells which otherwise would have been lost. On some occasions the wind was such that the parachutes were carried over land. This made recovery much less difficult. In fact, some were blown back to the firing point and were caught without striking the ground.

FIGURE 56. Breech-loading mortar, 81 mm.

Recovered fuzes were dried as thoroughly as possible with warm air blasts before being returned to the interested parties for examination.

8.4.7 Recovery by Use of Breech-Loading Mortar

The firing of shells into a rectangular trough filled with cotton waste was another very satisfactory method of recovery. The horizontal breech-loading mortar, shown in Figure 56, was used. The trough was 20 ft long. The construction of a metal detector for use in locating the shell within the trough was considered but was found to be unnecessary. The heat developed within the waste proved to be a sufficient indicator of the trajectory of the shell within the waste for rapid recovery by hand.

Chapter 9

ANALYSIS OF PERFORMANCE[a]

9.1 INTRODUCTION

9.1.1 Purpose

It is the purpose of this chapter to present an analysis of the performance of variable-time [VT] fuzes based on results obtained mainly by those methods of field testing described in the preceding chapter. Where possible, these results are compared with predictions of performance based on the theory of operation of the fuzes and on the characteristics of the fuzes obtained in the laboratory described in earlier chapters.

9.1.2 Sources of Data

Classification of Tests

Data on the field performance of the fuzes are not limited to the proving grounds or methods described in Chapter 8. As pointed out in Chapter 5, valuable data were obtained through the courtesy of various military agencies. Field tests may be classified roughly as follows:

1. Experimental tests performed during the course of development of a fuze. For any fuze that reached the mass production stage, the results of development tests are of no more than historical interest and are not given here.

2. Acceptance tests. For many fuzes, the acceptance tests performed by Army Ordnance provide voluminous data obtained under standardized test conditions. The conditions of the acceptance tests are described in an appendix to this chapter, and considerable use is made of the results under the title, "Performance under Acceptance Test Conditions," in various sections of the chapter.

3. Experimental tests performed with production fuzes or with fuzes closely approximating production design. These tests are of particular interest in that they include experiments to determine fuze performance under various conditions that are of importance in Service use but which are different from the acceptance test conditions. In addition to tests performed at the proving grounds, described in Chapter 8, this category includes certain important Service tests performed by military proving grounds.

The results of the above types of tests are given in the various sections of this chapter where the performance of the pertinent fuze is under discussion. Reports on the results of combat operations with VT fuzes are summarized in a separate section. As would be expected, these important results are of a qualitative nature, mostly statements of the judgment of observers working under very difficult conditions. Such results are not susceptible to quantitative analysis, and no attempt was made to subject them to such treatment.

Test Reference System

The inclusion of round-by-round results even in the microfilm supplement of this report is impractical. Reports on approximately 2,000 tests were prepared by the Ordnance Development Division of the National Bureau of Standards alone. There is, therefore, included in the microfilm supplement a set of tabular summaries of the results of individual tests identified by test number, and reference is made to these test numbers to show the sources of the data presented in the text. These summaries give the most important conditions of each test, and also references to the detailed report on each test. (Such summaries are not available for Army rocket fuze tests; in this case, reference is made directly to the detailed report in order to give positive identification of the

[a] This chapter was prepared by T. N. White, Jr., with the assistance of Rachel Vorkink, Alan Leiner, and Gladys Rabinow, Ordnance Development Division, National Bureau of Standards, and Paul F. Bartunek, Rosemarie Kilker, and David Fisher. In addition, H. F. Stimson, of the Heat and Power Division, National Bureau of Standards, prepared the sections dealing with afterburning, and Walter G. Finch, former captain in the VT Fuze Detachment of the Ordnance Department, prepared Section 9.6 on operational use. Captain Finch is now a graduate student at Johns Hopkins University. The summary, Section 9.7, was prepared by the editor.

source material.) Some of these summaries cover tests performed by military agencies, and in some cases the data were provided through courtesy of the military agency in advance of the official report of the agency. In all cases where an official report was available, reference is given to the official report. Every effort has been made to attain accuracy in these summaries, but it should be understood that there is no implication that the military agencies concerned are in any way bound by the results given or by the interpretation of the results presented in this report.

9.1.3 Description of Performance

The ideal representation of the performance of a fuze would be a diagram or model showing the frequency of bursts in space under each testing condition. A schematic one-dimensional representation is shown in Figure 1. This diagram is typical of bomb fuze performance, except that the region of proper functions has been expanded greatly (relative to the total length of trajectory) in order to show better the form of the proper function distribution.

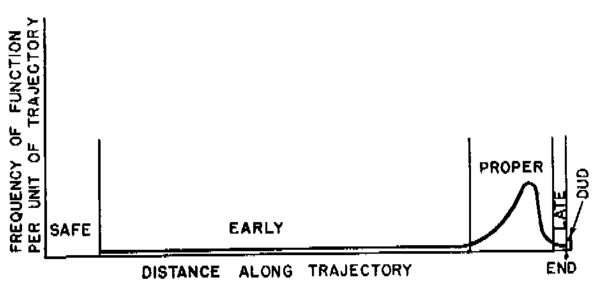


FIGURE 1. Schematic distribution of VT fuze functions along trajectory.

The data from most tests were much too limited to yield a representative frequency distribution. The bursts that occurred in each test were therefore classified as proper, early, dud, etc., according to the position or time of occurrence. This method gave the *score* of the test. For certain classes of burst, particularly the proper bursts, the average position and some measure of scatter were usually estimated.

Test programs such as acceptance tests, which yielded large masses of data, showed that there was no sharp dividing line between the different classes of burst. It was not always possible even to distinguish between a burst at the end of the flight and a dud. The method of classification of bursts was therefore to some extent arbitrary. For practical purposes this uncertainty is a matter for little concern. Inspection of Figure 1 shows that the proper burst score, which is the most important score, is little affected by the position of the limits within which bursts are classed as proper, provided these limits are placed well out on the "tails" of the proper burst "hump." Generally speaking, there was rarely any serious difficulty in distinguishing between proper functions and malfunctions, except in the very earliest stages of testing of a basically new fuze.

In the foregoing discussion it is tacitly assumed that a function should be classed as proper if the function is due primarily to interaction between the fuze and the target. In general, this is the criterion that was used in experimental testing. There is, however, another criterion that was used to some extent in acceptance testing. This criterion is derived from an assumption as to the space limits within which an air burst may be regarded as useful in inflicting damage in Service applications. In a few cases the limits so set were a little severe and were later broadened. The effect of such changes on aggregate acceptance test scores was, however, practically nil, and no attempt has been made to revise old scores in order to reduce all to a rigorously equal basis. It is also true that the differences between the two criteria mentioned above had a negligible effect on the estimates of performance.

Throughout this chapter, the terms burst and function are used interchangeably, as is the case in most of the reports of the Division 4 NDRC Central Laboratory, and it is only in rare instances that there is any important distinction between the two. However, for the sake of exactness it appears worth while to emphasize that it is the position of a flash or smoke from a spotting charge or high-explosive [HE] load that is actually estimated. The position at

[redacted]

which the fuze functions cannot be measured directly in dynamic tests.

9.1.4 Evaluation by Field and Laboratory Testing

Before considering the results of field tests, it is important to realize that the evaluation of any particular fuze design was not based solely on its field performance, although satisfactory field performance was essential to the final acceptance of a design. Dependence on laboratory data was particularly important for fuzes in the earlier stages of development. It is safe to say that if it had been essential to obtain statistically convincing proof of the value of every design change by means of field tests, very few fuzes would have reached the production stage during World War II. The success of each fuze development was dependent on the soundness of the engineering theory of action of the fuze (which involved various simplifying assumptions), the validity of laboratory testing conditions (which could only approximate field conditions), and field testing (which was limited by both the time and labor required to build fuzes, and by difficulties in duplicating service conditions).

Although the preceding remarks apply primarily to developmental work, they have an important bearing on the evaluation of production fuzes. In examining the data on field performance, the following characteristics will frequently be noted. 1. The data are voluminous for acceptance test conditions but, for many fuzes, quite scanty for other conditions (e.g., other projectiles or velocities). 2. There is frequent evidence of statistically significant but unexplained variations between results supposedly obtained under the same conditions or between observed and predicted performance.

Although a very large amount of field testing was done, it was impossible, under the conditions that existed, to test all fuzes under all important conditions. The available facilities had to be reserved for the most urgent problems. The value of engineering predictions based largely on laboratory data, as attested by the development work, and by the performance of the fuzes that were tested under a variety of conditions, provides a reasonable assurance that certain gaps in the pattern of field data need not cause great concern.

With regard to the statistically significant variations, it will be noted that they are in most cases too small to be of practical importance in the military use of the fuze. In some cases, explanations might be given in terms of the approximations involved in the theory, laboratory, or field testing of the fuzes. These explanations are usually mentioned only in those instances where the discrepancies are considered to be of a practical magnitude.

9.1.5 Terminology

FUZE NOMENCLATURE

In presenting the results of acceptance testing, the designations of Chapter 5 are used. The results of tests performed under other conditions were obtained in many cases with both production and pilot-production fuzes (see Section 9.1.2, class 3). Where a mixture occurs, the simplest Army Ordnance designation is used (e.g., T-51 for T-51, T-51-E1, T-51-E2, or M-166). The exact composition of the group is determinable through the reference system for tests.

Manufacturers' names are used to some extent on account of certain differences in performance of the same fuze produced by different manufacturers. Almost all of the important differences in general quality of performance were associated with fuze design rather than with manufacturer. However, in the study of the effect of certain factors on fuze performance, e.g., effect of altitude of bomb release on burst height, it is sometimes necessary to distinguish between manufacturers in order to obtain a strictly valid test of the particular factor under consideration.

For the sake of simplicity, certain obvious abbreviations are used for manufacturers' names.

TYPE OF FUNCTION

The most important terms and abbreviations

are given in Chapter 5. Additional terms and comments on usage in the older literature appear in the appropriate sections of this chapter.

Errors

Values given for the mean distance to a burst are calculated where possible from photographic data obtained by methods described in Chapter 8. Only where photographic data were not available are visual estimates used. Only in acceptance testing is a large quantity of visual data (camera obscura method) involved. The discussion of systematic observational errors is covered in Chapter 8. The values of standard deviation of a distribution and standard error of the mean that are given in Chapter 9 are calculated from individual observations of the test (or tests) involved. Except where stated, no attempt is made to allow for sources of systematic errors. In most cases these measures of precision are utilized only in the comparison of mean values obtained under like observational conditions, so that the systematic component of error is balanced out.

Methods used in estimating the probability of fortuitous differences are those available in standard modern texts.[98]

9.2 FUZES FOR 4.5-IN. ARMY ROCKETS

9.2.1 Introduction

This chapter section deals with the performance of T-5 and T-6 fuzes for the Army 4.5-in. rocket.

There was a large amount of testing that provided information on the performance of both the T-5 and the T-6 fuzes. For this reason, the discussion of the performance of the two fuzes is preceded by a section on tests that provided basic information on the performance of both fuzes.

It should be noted that in target firing at Corncake (Fort Fisher, N. C.) Proving Ground (700 ft from launcher to target) 0.4-sec SW-200 switches were used, while at Blossom Point (1,200 ft from launcher to target) 0.7-sec SW-200 switches were used.

The following terminology is used in this chapter. In firing from the ground, or from a plane, for function on approach to a ground or water surface:

E = Early function, a function within 5 sec of firing in the absence of any legitimate target.

M = Middle, or mid-flight function, a function that occurs more than 5 sec after firing but too soon to be regarded as a proper function on approach to the ground or water surface.

P = Proper function, a function that occurs on approach to the ground or water surface within limits of height that experience has shown to be reasonable for normal operation of the fuze. The term Pw or Pg may be used to indicate that the function occurred over water or over ground, respectively.

D = Dud.

N = Number of fuzes fired.

For the benefit of anyone who has occasion to refer to source material, it should be noted that at times the following terminology has been used: W for Pw; A (approach) for P. In firing at short range at a mock target (as in acceptance testing), the following terms have meanings different from those defined above.

E = Early function, any function occurring before the target at a distance so great that a proper function would be highly improbable.

P = Proper function, a function that occurs at a position such that, judging from experience, it may reasonably be attributed to normal interaction between the fuze and the target.

L = Late function, a function that occurs after the region of P's.

I = Impact function, one that occurs on striking the surface. In the source material and reports on target tests, the term T (target) has been used extensively for P. Also, L has been used for spontaneous late functions, with functions attributed to the passage over a land-water boundary or to approach to water classified as B or W, respectively. In most cases the number of functions in these classes was so small that subdivision of the L class appears unwarranted for the present purpose.

Although scores and scoring methods can be discussed best in connection with experimental results, a few preliminary remarks are desirable for purposes of orientation. Proper function scores are in all cases given as the number

[redacted]

of proper functions expressed as per cent of the total number of fuzes fired, excluding from consideration those rounds that did not have a fair chance, e.g., rocket blowups or rounds that passed outside of the region of action of a target.

Early function scores may be reckoned in different ways. For example, in the extensive special studies on the causes of early functioning, duds provided no information, and it was customary to exclude them from consideration in calculating the early function percentage. Fuzes that had functioned early could not again function in mid-flight, so it was customary to express the middle function score as a percentage of middles plus propers, usually excluding duds as in calculating the early function score.

These scoring methods, which were suitable for basic studies, are not directly interpretable into performance of T-5 and T-6 fuzes. The interpretation will be discussed after the data have been presented. At this point it is merely noted that a middle function would probably appear as a proper function in the T-5 application (provided the rocket passed reasonably close to a target). Further, since no correlation was found between middle and early functioning and since early functioning does not occur in the T-6 because of reliability of the arming mechanism, the early functions may be disregarded in estimating the performance of T-6 from many tests in which the SW-200 switches were used.

9.2.2 Tests Yielding Basic Information on Both Types of Fuzes

Early and Mid-Flight Functioning

On the basis of the principal causes of malfunctioning of the T-5 and T-6, the random functions have been divided into two classes, early and middle, as defined in the preceding section.[3, 5, 17, 32] Although the line of demarcation (5 sec) is somewhat arbitrary, it will be seen from the following discussions of the two types of functions that from a practical standpoint this division is quite satisfactory.

Early Functioning (Afterburning). On many rockets a radio proximity fuze is handicapped by malfunctioning which is due to afterburning of the rocket propellant (cf. Section 2.13). When flame issuing from the rocket nozzle is ionized, it increases the effective length of the rocket as an antenna, and makes a change in the radiation impedance. Sudden changes in the length of the flame make rapid changes in the radiation impedance and hence produce the same effect on the fuze as the normal target. For this reason fuzes are generally constructed so that arming is not completed until after the primary burning flames from the rocket have ceased. Frequently, however, there is a burning following the primary burning, known as afterburning, and it is well established that this afterburning is one of the major causes of malfunctioning of rocket fuzes. Static experiments were performed to establish the correspondence of the fuze performance with the properties of these afterburning flames. These experiments also showed that flame sometimes was present without pulses but that triggering pulses were not present without flame. Therefore, in order to avoid an excessive proportion of malfunctions, it is desirable to eliminate or control afterburning from the motor.[b]

For the best performance of the rocket, the pressure within the motor should decrease only slightly during the primary burning. The pressure within the motor, however, is strongly dependent upon the surface area of the propellant which is burning, so that after the surface has decreased by a small amount, the pressure has decreased by a larger amount. In order to maintain the pressure, the shape of the propellant used in rocket motors is such that its burning surface remains nearly constant throughout the primary burning. In the 4.5-in. Army rockets, which use solvent-extruded Ballistite, the grains of propellant are tubular and the burning proceeds both from the outside of these tubes and from the inside at the same time. The surface on the outside of the grains decreases and the surface on the inside of the grains increases at essentially the same rate,

[b] Early attempts to eliminate malfunctioning during the secondary burning period took several different forms. Plugs to close the nozzle after the main blast, or "sweeps" to remove residual powder, were tried. None of these methods gave satisfactory results.

so that the total surface remains nearly constant, except for the shortening of the length of the grains.

When burning has proceeded until the web of Ballistite has been burned through over a considerable portion of the grain, the surface, and therefore the pressure, is reduced to such an extent that primary burning is no longer supported. In the Army 4.5-in. rocket the primary burning stops at about 0.2 sec. At this instant, the temperature of the remaining Ballistite is very little greater than it was before the primary burning started, because the surface of the Ballistite, which was receiving heat, was being consumed rapidly. After the primary burning has stopped, and Ballistite is not being consumed rapidly, the residue of Ballistite is heated by radiation from hot metal parts within the motor. A secondary low-pressure burning begins then and continues until all the remaining Ballistite is either consumed or ejected.[c] This seldom lasts more than 4 sec.

The products of combustion of the Ballistite during the primary burning consist of some inert gases such as CO_2 and N_2 and also some incompletely burned products such as CO and H_2. The incompletely burned gases, when mixed with the oxygen of the air outside the rocket, are probably the cause of the luminous flame during the primary burning. During the secondary burning, there is probably an even greater proportion of flammable gases which can combine with the oxygen of the air to produce luminous flame. It seems to be a matter of chance, however, whether these flammable gases on issuing from the rocket nozzles will ignite or not. The constituents of the Ballistite also determine, to some extent, whether these gases ignite or not; for example, Ballistite salted with 1.5 per cent K_2SO_4 has much less afterburning than the unsalted Ballistite. The expansion ratio in the rocket nozzles may also have a determining effect upon the temperature and consequent ignition of these gases.

Since it was recognized that the burning of the residual Ballistite was causing malfunctioning of the fuzes, some method was sought to consume this Ballistite before the fuzes armed. It was suggested that a mixture of nitrate and picrate salts could be found which, when mixed with a suitable binder and pressed into pellets, would burn for 0.5 sec. Such pellets, when added to the propellant charge, were expected to consume the slivers of Ballistite and entirely eliminate all flammable material from the motor chamber before the arming time of the fuze. Section H of Division 3 of NDRC in Washington, and Division 8 of NDRC at Bruceton, Pennsylvania, cooperated in this search and developed "maintainer pellets," or "purge pellets" (as they were commonly called), for this purpose.

Tests had shown that when normal Ballistite was used, nearly 70 per cent of the fuzes functioned before 5 sec. Such functions were called early functions. The addition of certain pellets reduced the number of early functions to less than 20 per cent. Contrary to expectations, however, afterburning was not completely eliminated. Firings at night showed that afterburning often persisted continuously for an even greater time when pellets were used than when the standard charges were used, although the afterburning was not so brilliant as it often was without pellets. It is possible that the effectiveness of the pellets was due in part to the greater steadiness of the afterburning and in part to its reduction.

At about this time, during the development of these pellets, a variation in performance of the rounds without the pellets was noticed which was at first attributed to the particular lot of propellant which happened to be loaded in the motors. It was proven later, however, that the lot of propellant had little, if anything, to do with the fuze performance, but that the variations in performance were almost entirely dependent upon the interior metal parts of the rocket motor. It was found, for example, that the M-9A1 rocket motor gave about half the percentage of early functions which the earlier M-9 motor had given and the M-9A2 motor gave an intermediate performance.

The most striking discovery was that with a double supporting ring at the base of the trap on which the propellant was loaded there were about 67 per cent early functions, where-

[c] Insulation of various sorts was applied to trap wires and inside of motor but no improvement in performance was noted.

[redacted]

as with a single supporting ring at the base of the trap there were only about 25 per cent early functions. Later a scalloped ring at the base of the trap was developed by the Army as a standard for this rocket, and with it there were only about 18 per cent early functions. The early functioning on the rockets was reduced by this trap to about the same extent as by the pellets on the double-ring traps.

Subsequent experiments were made, using single-wire traps of different weights, and using varying amounts of metal near the nozzle end of the motor, but no explanation of the marked effect of traps has yet been found. Furthermore, extensive measurements of nozzle sizes, ratio of length to throat diameter, were made when the performance of later models of the M-9-type, with variations in nozzle dimensions, were found to give improved performance. These, however, shed no light on the problem.

Simultaneously with the development of pellets, work was done on salted powders. Some of the more successful ones reduced the percentage of early functions, with double-ring traps, to about 20 per cent. When a mixed load, part salted and part unsalted, was used, intermediate scores were obtained.

TABLE 1. Early function† scores* for T-5 fuzes on 4.5-in. Army rockets. Elevation is 60° or greater unless otherwise noted.

Trap ring	Motor	*E*	*M*	*Pw*	% *E*‡	% *M*
Load: regular double-base propellant						
Single wire	M-9	33	12	85	25	12
Single wire	M-9A1	4	9	34	9	21
Double wire§	M-9	443	45	175	67	20
Double wire	M-9A1	35	6	55	36	10
Scalloped	M-9	22	13	90	18	13
Scalloped	M-9A1	11	28	107	8	21
Load: regular plus 10 pellets						
Double wire	M-9	23	30	104	15	22
Load: salted powder						
Double wire	M-9	17	12	57	20	17

* Note: The better scores on the M-9A1 motors may be attributable to the rotation of this projectile, which is brought about by hand crimping of the fins.

† Including middle-function performance; see following section for discussion of middle functioning.

‡ Disregarding duds, i.e., 100 $E/(E + M + Pw)$.

§ 58 of these were at 45° quadrant elevation, 27*E*, 3*M*, 28*W*.

It should be mentioned that investigations were made of the effect of powder weight, of motor velocity, and of the dampness and temperature of propellant. In certain cases some change in the time distribution of earlies was noted, but there was no appreciable dependence of functioning scores on any of these factors.

In Table 1 scores for various motor, trap, and propellant combinations are given. Time distribution of earlies is shown in Figure 2.

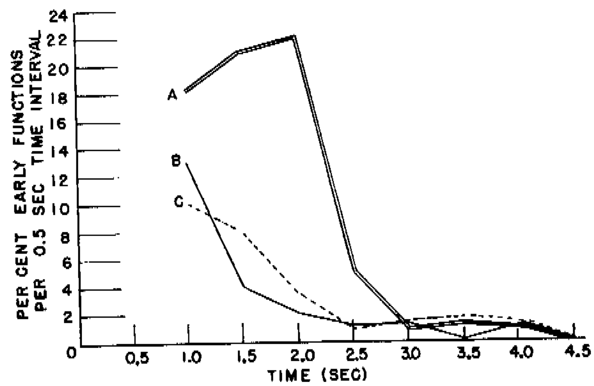


FIGURE 2. Time distribution of early functions, T-5 fuzes (high-angle firing): A, with double-wire ring at rear of trap; B, with single-wire ring at rear of trap; C, with purge pellets.

Middle Functioning. The principal known cause of the random functions with T-5 and T-6 fuzes classified as middle (after 5 sec) is faulty fin assemblies. Rounds fired, at 30-degree elevation, on 4.5-in. rockets with nonlocking fins give approximately 70 per cent such malfunctioning. By proper modifications (crimping) to insure locking of the fins in the open position, this percentage may be reduced to about 20 or less. Such expedients as brazing and welding the fins in the open position also lowered the middle-function score, in some cases quite markedly. However, since rigid fins prohibit the use of a smooth-bore tube as a launcher, emphasis was not placed on their development.

Following the discovery of the strong dependence of early functioning on the type of trap used, a comprehensive study was made of existing results to determine any relation that might exist between middle functioning and known variables (other than fin assemblies) such as motor traps and propellants. No dependence of middles could be found upon (1) trap construction, (2) type of propellant, including pellets and salted powders, or (3) frequency band of the fuze (i.e., Red, Yellow, or

[redacted]

Green). Here it should be mentioned that experiments were performed to test the effect upon fuze performance of loose joints, both between shell and fuze and shell and motor. It was shown that any reasonable looseness of these joints would not produce an increase in middle functioning.

When results were sorted according to manufacturer, however, statistically significant differences were found as follows:

Mfr.	Overall % middle	% middle in 30 sec*	No. of rounds on which % is based
A	14.3	12.1	938
B	29.1	24.6	598
C	26.0	22.0	78

* Thirty seconds is approximately the flight time for maximum firing elevation (42 degrees) prescribed by the Army.

Plots of "per cent still good" versus time, were made and found to take the form of exponential curves. When these curves were extrapolated back into the early-function period, it was found that from 5 to 10 per cent of the malfunctions scored as earlies should probably be attributed to the middle-function phenomenon.

A very satisfactory reduction of middle functions was found in units which had survived rather violent "shaker" testing in the laboratory (see Section 7.4). Forty-one units not subjected to such testing gave 22 per cent middles, while 27 shaker-tested units fired under similar conditions gave no mid-functions.

A summary of representative middle-function performance is given in Table 2. Figure 3 shows the time distribution of middle functions for some 64 rounds on Revere M-9 4.5-in. rockets with nonlocking fins (30-degrees quadrant elevation [QE]). This distribution, which shows no particular bunching of functions at any specific time interval, is typical of the T-6 middle-function performance.

Mutual Interference[6]

So far the discussion of random functions has been confined to rounds fired singly. It is evident that in multiple firing a serious problem might arise from sympathetic functioning, i.e., the triggering of one fuze by the functioning of a neighboring fuze.

The possibility of such functioning was investigated in a test where 60 T-5's, mounted on HE-loaded 4.5-in. rockets, were fired in 12 salvos of 5 each. The nominal time interval between successive rounds was 0.1 sec. The launchers, 10 ft long, were mounted in parallel with a space of 10 in. between centers and at an elevation of 50 degrees. The self-destruction [SD] switch of one fuze in each salvo, usually that in the middle position, was set to go at

Table 2. Middle-function scores for T-5 and T-6 fuzes on 4.5-in. Army rockets.

Fin type	Per cent middle*	No. of rounds mid and proper	Quadrant elevation (in degrees)	Fuze mfr.
T-6				
Locking, factory crimped	19	91	25–40	B
Nonlocking	69	106	30	A, B
Hand crimped (locking)	21	85	30	B
Hand crimped (locking)	15	59	70	A
Crimped and brazed	23	47	70	A (T-5)
Welded, single thickness	10	49	30	B
Welded, double thickness	7	14	40	A
Welded, double thickness	28	32	60	A
T-5, shaker tested				
Hand crimped	4	45	45	D
Hand crimped	0	27	70	D
T-5, controls for shaker tested				
Hand crimped	22	41	70	D

* $\%M = 100\ M/(M+W)$.

2.5 sec, so that one fuze would be certain to function before the normal time for SD functioning (usually between 6 and 12 sec).[d]

Results of the test were somewhat complicated by several factors.

1. Not more than half the fuzes set for an early SD time functioned during the desired period. (This meant that only a very small amount of data covering the useful portion of the T-5 flight could be obtained.)

[d] T-5 fuzes normally come equipped with this type of switch although discussions in previous sections pertaining to middle functioning of the T-5 fuzes were confined to results with fuzes in which the SD switch had been shorted out.

2. Variations in initial velocities and irregularities in firing intervals made distances between rockets in flight quite uncertain.

3. Times to function as determined by stopwatch could not be considered very accurate.

In order to make allowance for errors in timing and to provide some means of analyzing the data, the following method was used. To each round there was assigned a 0.4-sec interval spanning the given time to function. A reasonable measure then of the presence of sympathetic functioning was a comparison of the number of overlapping intervals within salvos and those between salvos.

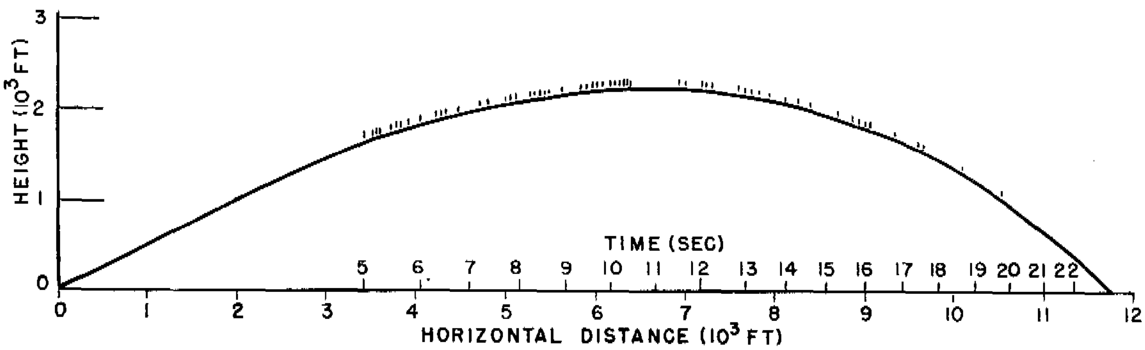


FIGURE 3. Distribution of functions in mid-flight, T-6 on M-9 with nonlocking fins. Elevation: 30°. Eash dash on trajectory shows approximate position of a function.

Statistical analysis showed good agreement between expected (fortuitous) and observed members of overlapping pairs within and between salvos. This indicated that *no appreciable sympathetic functioning occurred.*

MISCELLANEOUS

Spin Effect on Arming. The SW-230-type arming switch, when used on nonrotating projectiles, is very reliable. When, however, this switch is subjected to rotation in excess of a certain minimum speed, faulty performance is to be expected. Laboratory testing has shown that for rotational speeds up to 600 rpm normal functioning occurs; above 900 rpm, the switch does not arm at all; and between these two extremes there is an increasing time required to complete arming.[13] The effect was of practical importance because a slight twist on the fins of an M-8 rocket might produce enough rotation to interfere with the proper operation of the arming switch. In most cases the rotation of the projectiles was brought about by the deformation of fins during the crimping process. A series of field tests confirmed laboratory results on the delay or prevention of arming[7, 16] due to rotation. A general conclusion was that the effect became serious if the fins were tilted more than 2 degrees from their proper position.

Rain Effect. The T-5 (or T-6) fuze when fired in moderate or heavy rain cannot be depended upon to ride through to proper function. The triggering pulses from impact with the drops can be significantly reduced, however, by the use of Lucite caps cemented over the conical surface of the fuze. The following gives a comparison of function scores for rounds fired during rainfalls of comparable intensity[e] with and without such "rain caps."

	E	*M*	*Pw*	*D*
With Lucite caps	1	0	8	1
Without caps	5	1	3	2

Photographic measurements of function heights indicated no appreciable effect on sensitivity from the Lucite caps.

9.2.3 Performance of T-5 Fuzes

SAFETY AND ARMING

General Considerations. The arming switch of the T-5 is so designed that arming occurs

[e] Data on frequency and size of drops were obtained by exposing pieces of specially prepared cloth to the rain for measured intervals of time. Where water hits this cloth a permanent colored spot is produced.[9]

[redacted]

at a definite time after the end of burning. The distance from the launching point to the point of arming is therefore obtainable by adding to the burning distance the product: (mean velocity during switch operation) $\times$ (time of switch operation). As the temperature of the rocket propellant is increased, the burning distance decreases and the peak velocity increases. The arming distance of the fuze is therefore a function of temperature.

When the rocket is launched from a plane, the distance that is of interest is the distance from plane to rocket at the time of arming. In general this distance will be less than the distance determined in a ground launching test at the same temperature. This decrease in distance is due to the greater air drag on the rocket, which travels at a higher speed when launched from a plane. This statement is true in cases of firing at moderate altitudes. In case of firing at high altitudes, there may be a compensating effect due to the higher efficiency of rockets in rarefied atmosphere. The arming distance of the T-5 is therefore a function of the temperature of the rocket propellant, the speed of the launching plane, and its altitude.

Sufficient data are not available for exact estimation of the effects of these factors on arming distance. Approximate calculations indicate that the effects can be neglected, for practical purposes, under a fairly wide variety of conditions. The possibility that they might be of importance under extreme conditions should not be disregarded.

Switch Reliability. 1. *Failure to arm.* Specific data on failure to arm, as such, are not available. However, dud scores in acceptance testing establish a reliable measure of the upper limit of SW-200 switch failure. The overall dud score for 4,334 rounds was 3.6 per cent. It is reasonable to assume, therefore, that something less than this percentage of switches failed to arm.

2. *Safety and lower limit for arming.* Data on time and distance to arming from direct measurements on units set to function on arming with 0.7-sec switches, are very scanty. Again, reference may be made to acceptance results to establish lower limits. In Figure 4 is given the distribution of 226 early functions (Blossom Point data, all on M-9) in terms of distance from the launcher. From this curve it may be seen that less than 1 per cent of the fuzes had functioned at the 550-ft point and none at 525 ft. Although there is no certainty that some fuzes had not armed before the 525-ft mark from the standpoint of safety, it is relevant to emphasize the fact that no functions were observed before this point. For standard

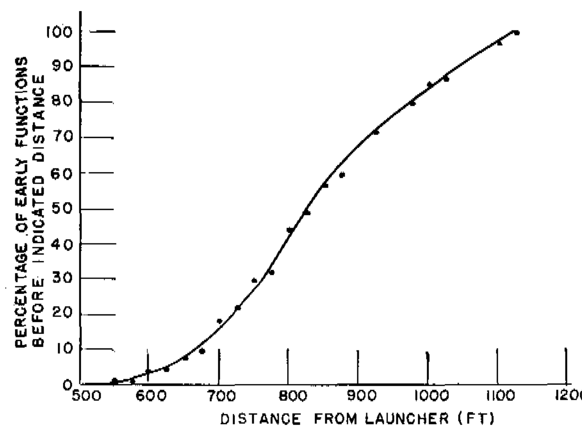


FIGURE 4. Cumulative percentage of early functions, MC-382 acceptance testing.

test conditions (ordinary temperatures and 30 grains of propellant) this distance of 525 ft corresponds to a 0.7-sec flight time.

3. *Upper limit for arming.* The determination of the time or distance at which all fuzes (excluding duds) will become armed is somewhat uncertain. The situation is complicated by the effect of motor spin upon the action of the switch. See Section 9.2.2 for discussion. An estimate of an upper limit may be made from the number of live units (total minus duds) which functioned either early or on target in acceptance testing. Blossom Point data show that at least 98 per cent of the switches were closed at 1,200 ft (1.4 sec, approximately). Results of the few arming tests, however, indicate that when a reasonably satisfactory fin assembly is used, the majority of the switches will be armed after 1 sec of flight.[11]

Risk of Premature Function. The possibility of the occurrence of a function before normal

time for closing of the arming switch is very remote. In the assembling of hundreds of standard units for acceptance testing and attendant experimental work, no switch was ever found to be in the armed position. Also in firing tests no premature functions were ever observed on HE-loaded rounds. With inert-loaded rounds using the highly sensitive spotting charges (see Chapter 8) the safety features of the powder train barrier do not apply. However, even in these cases no fully verified premature functions were reported. Occasionally (actually only twice in many thousands of tests) observers claimed to see the spotting charge operate as the rocket left the launcher. Since visual recognition of the spotting charge during the burning of the rocket propellant is extremely difficult, the validity of even these rare observations is dubious.

Performance under Acceptance Test Conditions

The results of acceptance testing (horizontal firing at a target about 1,000 ft out, see Section 9.8 for requirements for acceptance) form the greatest mass of data available concerning performance of T-5 fuzes under fairly uniform firing conditions. Although there were some differences in conditions at the various proving grounds, the setups were essentially the same. Details of procedure at the different locations may be found in Chapter 8.

In Table 3 scores of acceptance tests are listed according to manufacturer and proving ground. Detailed analysis of the results obtained at Corncake (Fort Fisher) and Blossom Point may be found in reference 4. Although these scores lead to a reasonably good estimate of the overall performance for T-5 fuzes fired under acceptance-testing conditions, two facts should be pointed out: (1) individual scores and variations therein cannot be taken at face value as indicating corresponding variations in manufacturing quality; nor (2) can exactly the same performance as indicated by these acceptance results be expected of fuzes fired under

TABLE 3. Acceptance testing results for T-5 fuzes.

Manufacturer	Proving ground	Lot No.	No. fuzes tested	Per cent *P*	*E*	*L*	*D*
Emerson	CC*	1–8, 10, 11	140	78.6	13.6	3.6	4.3
	BP†	9 and 12–59	613	80.9	13.1	2.8	3.3
	A‡	60–65, 71–97	338	83.4	11.2	1.8	3.6
Total			1,091	81.4	12.6	2.6	3.5
Friez	CC	1–4	64	75.0	17.2	0	7.8
	BP	5–12 and 15	101	89.1	3.0	1.0	6.9
	A	13–14, 18–26½	120	86.7	8.3	5.0	0
Total			285	84.9	8.4	2.5	4.2
GE	CC	1–5	70	74.3	17.1	2.9	5.7
	BP	6–35	347	86.5	10.1	0.9	2.6
	A	36–52, 55, 57–78	429	79.5	16.6	1.6	2.3
Total			846	81.9	13.9	1.4	2.7
Philco	CC	1–11	166	73.5	14.5	3.6	8.4
	BP	12–58	570	83.5	11.9	0.9	3.7
	A	59–77, 85–94, 98, 100, 102, 104–109	380	84.2	10.5	2.4	2.9
Total			1,116	82.3	11.8	1.8	4.1
Westinghouse (Mansfield)	CC	1–8	114	73.7	13.2	7.9	5.3
	BP	9–44	458	79.5	15.1	1.3	4.1
	A	45–61, 65, 67–77	360	81.1	14.7	1.7	2.5
Total			932	79.4	14.7	2.3	3.6
Westinghouse (Baltimore)	BP	1–4	64	62.5	25.0	10.9	1.6
All			4,334	81.2	13.0	2.2	3.6

* Corncake Proving Ground, Fort Fisher, N. C.
† Blossom Point Proving Ground.
‡ Aberdeen Proving Ground, Aberdeen, Md.

[redacted]

conditions unlike those of acceptance work, i.e., high-angle, plane-to-plane.

It has been shown earlier that such factors as motor type, propellant, and kind of trap may very markedly affect early functioning. Still other factors such as temperature and varying distances from position of arming to target must be taken into consideration. Since it is not possible to separate these effects entirely, lot-to-lot variation in performance must be viewed with caution; specifically, for example, the apparent improvement in scores of tests conducted at Blossom Point over those done at Corncake must not of necessity be taken as an indication of improved manufacture, but rather as the possible result of a combination of many factors including perhaps even unknown changes in test conditions.

Entirely apart from experimental test results, this view is amply supported by a study of the acceptance test performance. For example, Figure 5 shows that the February 1943 early functioning performance of fuzes of all manufacturers was poor on Revere rockets, but good on Budd rockets or Revere rockets fitted with Budd fins. The strikingly uniform improvement in the subsequent performance of all fuzes on Revere rockets is not accompanied by any similar change on the Budd or modified Revere rocket. No convincing explanation has been found for the improvement on Revere rockets.

In view of the results of later experimental testing where attempts were made to control increasingly larger numbers of variables (which hitherto either had remained unnoticed or had not appeared as relevant) the performance of production fuzes appears to be satisfactorily uniform. The overall score as given in Table 3 gives 81 per cent proper; it is safe to say that with a satisfactory trap-ring-motor-propellant combination a slightly higher score could now be expected. (Much of the acceptance work was done before high-angle testing showed the importance of these three factors.)

Effect of Distance to Target on Performance

Compared with those in actual combat use, the distances between arming and target in acceptance testing were somewhat limited. This means that in actual use, then, there would be greater opportunity for the fuze to malfunction before reaching the proper destination and, if so, proper function scores would be lower.

Since the period for early functioning as defined in Section 9.2.2 is about equal to the minimum time taken for the SD feature of the T-5 to work, estimates of reliability for combat use (for ranges longer than the acceptance test range) can easily be made from results of high-angle testing. The early functions remain classified as early and all other functioning rounds become proper (see Section 9.2.2 for representative scores). Figure 2, in Section 9.2.2,

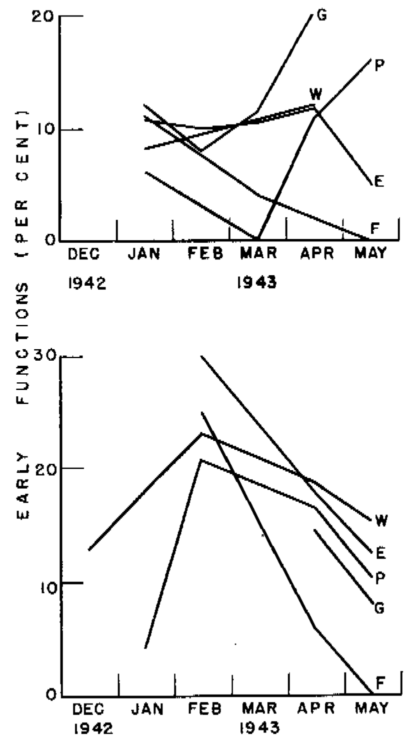


FIGURE 5. Early function performance in acceptance testing of MC-382 rocket: Budd or Revere with Budd fins (top); Revere, inert-loaded or empty head (bottom). G General Electric, E Emerson, F Fricz, P Philco, W Westinghouse.

shows time distribution of early functions for various types of trap. When adjustment is made for a 4 per cent dud score, the following per cents proper obtain for rounds passing within

[redacted]

radius of action [ROA] of target for the indicated flight times.

Flight time (sec.)	Estimated per cent proper Worst trap	Best trap
1.0	85	91
2.0	41	84
3.0	35	82
4.5	32	81

These values are based on the assumption that performance for combat firing will be comparable to high-angle results. The early function scores in high-angle firing during the first 1.3 sec of flight and those for target testing (about 1.3 sec to target) are comparable when allowance is made for variations in motor construction and propellant. This fact gives assurance that the above estimates are fairly reliable.

Effect of Dispersion of Trajectories on the Distribution of Bursts about a Target

Analysis by the Applied Mathematics Panel, NDRC,[41] of results with some thousand fuzes tested on the mock-plane target (1/5 scale of B-25 bomber) at Blossom Point indicated, for firing from astern, the following dependence of target functioning upon distance of passage from target axis (impact parameter).

Impact parameter (ft)	Per cent of total rounds less duds and earlies functioning on target
10	100.0
20	99.9
30	99.3
40	95.0
50	79.7
60	50.8
70	21.5
80	5.5
90	0.8
100	0.1

The distribution of target functions for rounds fired through ROA for acceptance results is shown in Table 4. In Figure 6 are shown graphically the distributions for two values of impact parameter. For empirical equations to represent these distributions see reference 41.

Effectiveness in Plane-to-Plane Firing

A study was also made by the Applied Mathematics Panel to determine the probability that a single 4.5-in. rocket fuzed with T-5 (when fired from 1,000 yd directly astern) would disable an enemy twin-engined bomber (Ju-88). It was assumed that the rocket trajectories have circular symmetry about the longitudinal axis of the aircraft; specific dispersion data used were from results at various proving grounds. The value of fuze reliability used was based on Blossom Point and Corncake data. Estimates of damage by a projectile were based on material presented in reference 40; these estimates considered damage not only to the engines but to various vulnerable portions of the plane.

Calculations were made on two assumptions: (1) that the plane could not return to base on one engine, and (2) that the plane could return to base on one engine only. The following results were obtained:

Standard deviation* of firing errors (ft)	Probability of disabling the aircraft
Aircraft assumed unable to return on one engine	
25	0.207
50	0.106
75	0.057
Aircraft assumed able to return on one engine	
25	0.143
50	0.066
75	0.035

* With a 50-ft firing error (standard deviation) the chance of a direct hit is about one in a hundred.[41]

Effectiveness in Plane-to-Ground Firing[48]

In a test to compare the effectiveness of VT-fuzed and contact-fuzed rockets against personnel in slit trenches, 100 rounds of 4.5-in. rockets (T-22, with T-23 fins), fuzed with T-5 were fired from a plane over the effect field (Eglin Field) described in Section 9.4.5. (Testing with contact fuzes was discontinued after 18 rounds fired—to ricochet—did not ricochet properly, and gave an excessive number of low-order functions.) Twenty each of the T-5's were fired in dive angles of 10, 20, 30, 40, and 50 degrees.

Table 5 shows the number of casualties (scored as in Section 9.4.5) per burst at various heights, for 4 degrees of shielding.

It is important to note that the significance of "zero shielding," in this test, is somewhat different from that appearing in some of the literature on the effectiveness of air-burst pro-

jectiles. In this test the vulnerable area presented to any fragment moving in a horizontal, or upward direction, is zero (unless the burst occurs inside a trench) in the case of zero shielding. Although this definition is not beyond criticism, it is considered to be more practical than one alternative which considers that the maximum possible vulnerable area is presented to a burst occurring in the plane containing the targets. The principal weakness of the latter definition arises from the fact that enemy troops would very rarely be distributed in a mathematically plane surface. For a fuller discussion of this topic the reader is referred to Section 9.4.5.

TABLE 4. Distribution of functions in target firing of T-5 fuzes on Revere inert-loaded motors at Blossom Point, March 1943 to March 1944.

	Impact Parameter $p = \sqrt{y^2 + z^2}$ (ft)											
z (ft)	8	1	3 1	8 2	3 2	8 3	3 3	8 4	3 4	8 5	3 58	Total
15									2	1		3
10									1	1		2
5									1	1		2
0						1			4	2		7
—5					4	4	1		2	2		13
—10				2	10	8						20
—15				2	5	10	2					19
—20			1	6	21	6	1		1	1		37
—25			5	52	100	41	4					202
—30			2	73	180	68	6		5	1		335
—35			1	45	130	72	4		2	7		261
—40				2	29	17	3		9	2		62
—45					1	1			5	1		8
—50												
—55												
—60												
—65												
—70					1							1
Subtotal			9	182	481	228	21		32	19		972
E		2	2	20	51	16	2					93
L					2			1	6			9
D			2	9	14	3						28
Total		2	13	211	548	247	23	1	38	19		1,102

TABLE 5. Casualties as a function of burst height.

Burst height (ft)	Casualties per burst: 12-in. shielding (conservative)*	12-in. shielding	6-in. shielding	0-in. shielding
0–5	0.6	0.8	1.0	1.9
6–15	1.8	2.3	3.0	5.9
16–30	1.8	3.1	3.7	6.6
31–50	2.4	3.7	4.3	6.1
51–80	1.4	2.2	2.7	3.9
81–125	1.2	1.5	2.5	4.2

* Counting only those bottom hits more than 6 in. from nearest edge of box (5 sq ft vulnerable area instead of 12 sq ft).

Figure 7 shows (1) mean burst height versus

[redacted]

dive angle, (2) casualties per burst versus dive angle, (3) casualties per burst versus burst height.

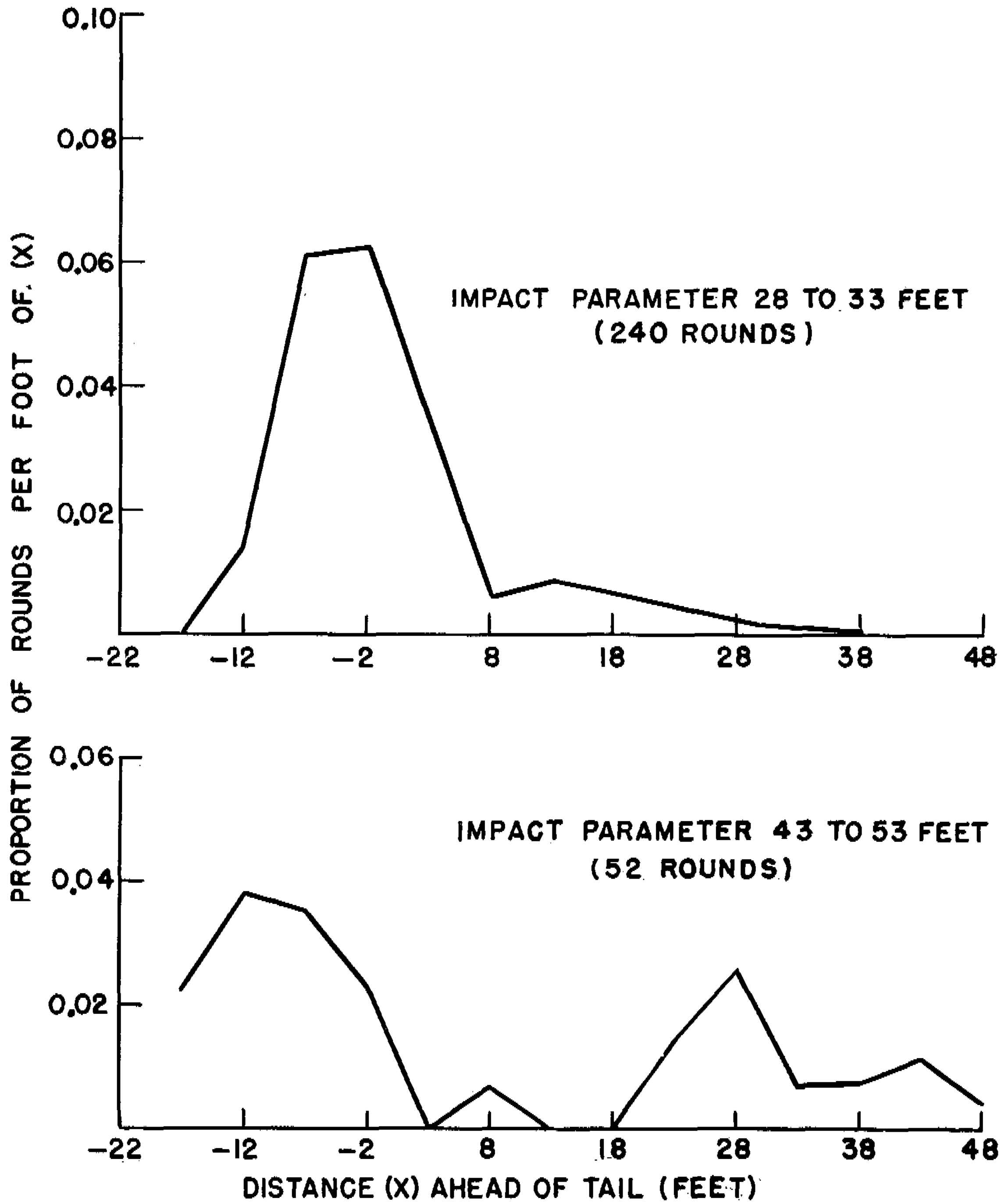


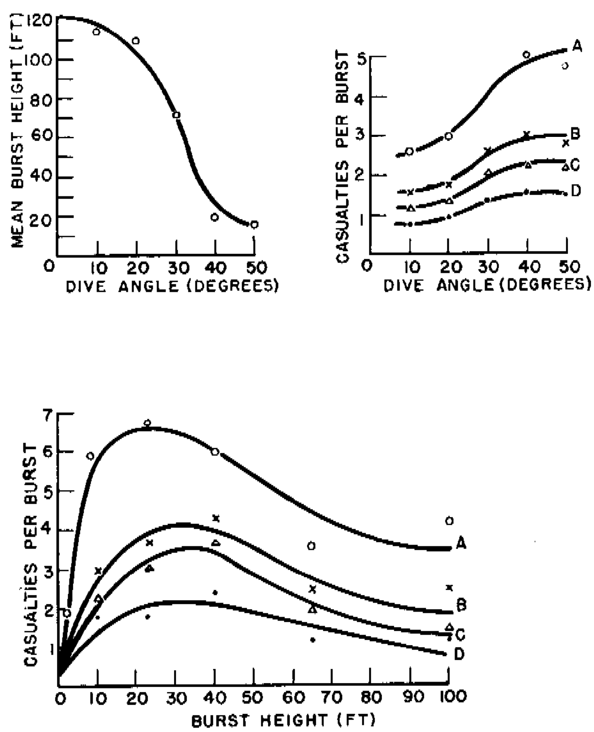
FIGURE 6. Distribution of T-5 bursts along trajectories near fixed mock-plane target.

In actual combat, the casualties per burst would depend on the degree of concentration of the enemy troops and on the shielding. The data indicate that the *relative* effectiveness of air and ground bursts is not critically dependent on the degree of shielding, and there is no reason to expect that it would depend on the concentration of the enemy.

At the optimum burst height, about eight

[redacted]

times as many casualties were obtained as with ground bursts. On account of scatter in the burst heights, and differences in the reflection coefficient of various terrains, the optimum height cannot be realized in combat. However, the results show a rather wide range of burst heights for which the relative advantage of the



Code	Depth of shielding (in.)	Vulnerable area (sq ft)
A	0	12
B	6	12
C	12	12
D	12	5

FIGURE 7. Effectiveness of T-5 fuzed 4.5-in. rockets for various degrees of shielding—plane-to-ground firing: mean burst height as function of dive angle (top left); casualties as function of dive angle (top right); casualties as function of burst height (bottom).

air burst over ground burst is larger and nearly independent of the degree of shielding. This useful range of burst heights is most closely realized by firing in the steeper dives. Again this is not at all critical, but dive angles in excess of 30 degrees are indicated (cf. footnote c of Chapter 1).

9.2.4 Performance of T-6 Fuzes

SAFETY AND ARMING

General Characteristics of Arming Switches. Mechanically the arming switch for the T-6 is the same as that for the T-5. In addition further delay is introduced by means of an electric resistance-capacitance circuit. When mechanical arming is completed, a switch is closed which allows current to flow from the battery through an arming resistor into the arming condenser. The voltage on the condenser rises until it is large enough so that a positive pulse into the thyratron will cause it to fire and set off the detonator. (There is a region of time just before the condenser is charged sufficiently to complete the arming cycle during which a pulse on the input to the thyratron will cause it to become conducting. This removes a portion of the charge accumulated, without firing the detonator. This phenomenon, called "dumping" (cf. Section 3.3.6), occurs only if the fuze receives a firing signal sometime during the interval when the condenser has voltage enough to ignite the thyratron but does not contain energy enough to fire the detonator. If such an accidental "dumping" signal occurs, the circuit automatically recovers and arms at a time about 20 per cent longer than normal. This phenomenon does not cause serious trouble under ordinary circumstances.

Arming Time and Distance. Direct measurement of arming time cannot be made for switches incorporating an RC delay (see Section 8.3.7). However, from laboratory determinations of values of the various electric components, along with measured times to mechanical arming, satisfactory predictions of arming times for the T-6 can be made.[23, 24]

The validity of such predictions is substantiated by field tests of Navy rocket fuzes (see Section 9.3.2) in which fuzes were "pulsed" during flight by a transmitter located on the firing range. Such tests do not determine the arming time of an individual fuze, but they do give an experimental lower limit on the fraction of fuzes fully armed at any given time.

Figure 8 shows the per cent of fuzes armed as a function of time and of horizontal range for rounds fired on Revere 4.5-in. rocket ($V_0 =$

840 fps). It will be seen that no fuze can function before a horizontal range of 800 yd and 95 per cent will be armed at 1,650 yd. (If the projectile passes within 150 ft of crests or other suitable targets before arming is complete, "dumping," as mentioned above, may occur. Under these conditions the percentage of fuzes armed may be slightly reduced at ranges up to 2,000 yd.)

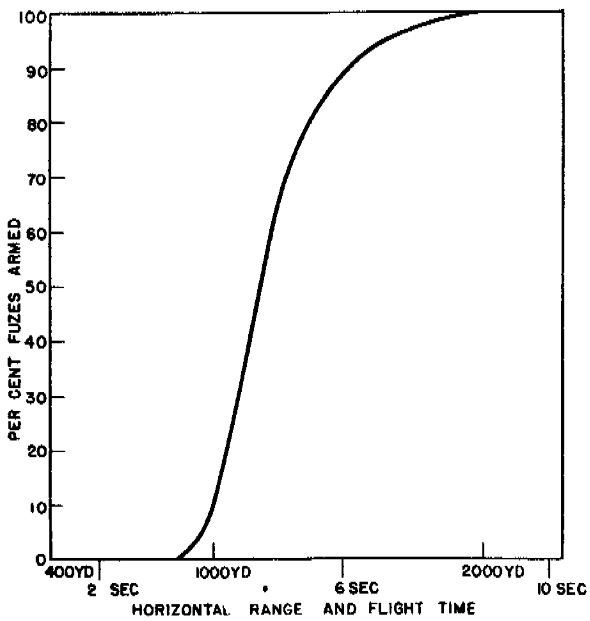


FIGURE 8. Cumulative per cent of T-6 fuzes armed as function of flight time and horizontal range.

RELIABILITY

No acceptance testing, as such, was done with the T-6 fuze. Since except for the arming switch, T-5 and T-6 are identical, estimates of reliability may be made from results of experimental high-angle testing of the T-5. An intensive study[32] of middle functions, random functions occurring after 5 sec, among some 1,600 rounds yields the following estimates of performance as a function of flight time.

Flight time (sec)	Per cent proper function Mfr A	Mfr B
10	92	88
15	89	82
20	87	77
25	85	74
30	84	71
35	83	70
40	82	68

The above percentages are based on rounds fired on 4.5-in. rockets with reasonably satisfactory fin assemblies. For discussion of the effect of fins on malfunctioning of the T-6, see Section 9.2.2.

EFFECTIVENESS

In tests of the relative effectiveness of 4.5-in. Army rockets using T-6 fuzes, PD M-4 fuzes set for ricochet air bursts, and PD M-4 fuzes set for superquick action, 260 rounds were fired over an effect field at Fort Bragg, North Carolina.[50] The field contained 1x6-ft boards spaced 5 yd apart, laterally and longitudinally. The boards were laid in shallow trenches with top surfaces 1 in. below ground level. On each round which burst on the effect field, the number of boards hit by at least one fragment which penetrated at least ¼ in. into the wood was counted.

The results are given in Table 6.

TABLE 6. Comparative effectiveness of T-6 fuze and PD M-4 fuzes set for ricochet air burst and for superquick action.

	Total No. of rounds fired	No. of rounds on effect field	Average height of burst (ft)	Average No. of targets hit (per round)
T-6	76	20	60	21.2
PD M-4, ricochet air burst	85	10	15	16.8
PD M-4, superquick action	99	20	..	4.4

These results, where heights are visual estimates, are quantitatively somewhat different from those obtained in T-5 testing at Eglin Field, where heights were photographically determined. (See Figure 7.) In the test of the T-5, greater effectiveness was observed at a burst height of 17 ft than at one of 60 ft. The Fort Bragg results do agree with those obtained at Eglin Field, however, in that they indicate a fourfold or fivefold advantage, over a contact burst, of an air burst occurring over a considerable range of heights.

[redacted]

9.3 NAVY ROCKET FUZES

9.3.1 General

This section concerns the performance of the VT fuzes which are intended primarily for use on rockets as follows:

Fuze Navy ord. designation	Fuze Army ord. designation	Use	Rockets
Mk-172 Model 0	T-2004	Plane to ground	AR 5.0
Mk-171 Model 0	T-30	Plane to plane	HVAR

Throughout the section the following rocket designations, established by the California Institute of Technology [CIT], are used for convenience. The aircraft rocket [AR] 5.0 is used to designate the 5.0-in. Mk-1 shell with the 3.25-in. Mk-7 motor. The high-velocity aircraft rocket [HVAR] refers to the same shell, or the 5.0-in. Mk-5 shell, used with the 5.0-in. Mk-1 motor. Considerable testing was performed with the AR 3.5, denoting the 3.5-in. Mk-5 or Mk-3 (16 lb) shell and the 3.25-in. Mk-7 motor combination.

The same scoring terminology and methods that are used for the Army rocket fuzes (see Section 9.2) are applied to the Navy rocket fuzes.

The mass production model of the T-2004 fuze was subjected to two stages of acceptance testing. The first stage, the "metal parts" acceptance test, was applied to a sample from each manufacturers' lot of approximately 1,000 "metal parts assemblies," which constituted a "metal parts lot." A spotting charge was used, and the rockets were not loaded with high explosive. Following acceptance, these assemblies were loaded with the few additional explosive components necessary to make complete fuzes, and the lots were usually combined into much larger lots known as "ammunition lots." The second stage was the ammunition lot acceptance test, applied to a sample from each ammunition lot, to check on the safety and reliability of the complete fuzes that were subsequently shipped to the using Services. A discussion of composition of ammunition lots and the relation between their performance and that of the metal parts lots is given in Section 9.4.3. Procedures for acceptance testing are outlined in an appendix to this chapter.

The large difference in overall sensitivity makes it desirable to treat the T-30 and T-2004 separately except for their arming characteristics. The latter are identical mechanically but differ in the amount of RC delay.

The relation between early functioning and afterburning is discussed under the T-30, since the problem is of much greater importance with the fuze that has the greater sensitivity and shorter arming time. Also, the afterburning of the HVAR is much more serious than that of the AR.

Section 9.2.2 should be consulted for a discussion of basic considerations relating to afterburning as well as for the background provided by experience with the T-5 Army rocket fuze. Conclusions concerning afterburning and early functioning of VT rocket fuzes in general are given at the end of Section 9.3.3, with particular reference to the T-30 and the Navy rockets.

9.3.2 Safety and Arming

General

The arming mechanism of the VT fuzes for Navy rockets is so designed that mechanical arming occurs when acceleration of the rocket ceases. Complete arming is delayed somewhat further by the use of an RC circuit.

Mechanical arming tests should provide data that are in general agreement with the burning times and distances of the rockets. No exact comparison is practical, however, since burning does not cease abruptly, and mechanical arming occurs at some time during the final "tapering off" of the burning.

The values of the RC arming network follow.

Fuze	R (megohm)	C (mf)	RC
T-2004	1.5	1.0	1.50
T-30	0.82	0.90	0.74

The average RC delay should be approximately equal to the product RC in seconds (see Section 3.3.6). For the sake of completeness tests with fuzes having other values for R and C are included in the following analysis.

In addition to tests of arming performance, there are summarized the results of a safety test. This test, which was performed primarily as a check on the safety of the value adopted for arming distance, is of particular importance because it was conducted under conditions simulating rather closely those of Service use of the fuzes.

Mechanical Arming Performance

The most accurate data on mechanical arming performance are probably those obtained in the experimental tests, summarized in Table 7,[56] in which most of the arming distances were determined photographically. Arming times (stopwatch measurements) ranged from about 1.0 sec at the higher temperatures to 1.6 sec at the lowest. The distances given in Table 8, from ammunition lot acceptance tests, were calculated from stopwatch measurements of arming time. Making due allowance for timing errors, the values agree reasonably well with those in Table 7.

For an analytical comparison of temperature effects on arming distance with temperature effects on burning distance, reference 37 should be consulted. Here it is sufficient to note from Table 7 that the effect of temperature on arming distance is practically negligible throughout a rather wide temperature range.

The relatively large arming distance observed with the AR 3.5 is probably due to the lower efficiency of the propeller at the high speed of this rocket, which is about the same as the velocity of the HVAR.

The best estimate of spread in mechanical arming distances (from Table 7) is given in Table 9.

From an inspection of Table 7 it is evident that there is a lower temperature limit, in the neighborhood of —20 F, for the reliable operation of the mechanical arming device with the AR 5.0. At —20 F, about half of the arming mechanisms failed to function. This limit arises from the fact that a certain minimum acceleration is required for arming of the fuzes. Tests by Army Ordnance indicate an upper temperature limit in the neighborhood of 110 F. An upper limit arises from the fact that the propeller must make a minimum of approximately 100 turns before acceleration falls below a certain value. For a complete discussion of the mechanics of the arming device see Chapters 4 and 5.

Table 7. Results of experimental FOMA tests.

No. of units	Score FOMA-D-L	Mean powder temp (degrees F)	Mean arming distance (ft)	Standard error of mean (ft)	SD of individual arming distance (ft)
		Bowen and GE T-30 units on AR 5.0			
10	9-1-0	70	461	23	68
20	10-9-1	—20	484	13	42
10	9-1-0	—10	476	16	49
10	9-1-0	0	465	19	58
10	10-0-0	80	439	5	16
		Philco T-2004 units on AR 3.5			
16	14-1-1	71	596	10	39
		Philco T-2004 units on AR 5.0			
15	14-1-0	90	445*	..	..
10	9-1-0	79	415†	13	38

* No photographic data of arming distances are available for this test. The average arming distance (445) was computed by assuming the average velocity in this test to be the same as the average velocity of similar rockets of other tests when fired under similar test conditions. The arming distance was then computed from the average speed and the observed arming time (1.086 sec).

† This figure is based on the photographic data of only 3 units.

Results of Pulsing Tests to Obtain Total Arming Distances of T-30 Fuzes

Data are provided by a number of tests designed to determine the spread in arming times and arming distances of T-30 fuzes[31] on the

[redacted]

AR 3.5. In these tests each fuze was "pulsed" by a transmitter at a certain point in its flight to determine whether or not it was armed. The experimental technique is covered in Section 8.3. The tests are very difficult to perform and the data are, therefore, rather limited.

TABLE 8. Results of Philco acceptance FOMA tests of T-2004 fuzes on the AR 5 rocket.

PA lot No. PA-315	No. of units	Score FOMA-D-L-I	Powder temperature (degrees F)	Mean arming distance (ft)
2	10	10-0-0-0	72	458
3	10	7-0-1-2	72	
4	10	9-0-0-1	59	542
5	10	8-2-0-0	..	453
13	10	10-0-0-0	82	404
3	10	10-0-0-0	83	554
6	8	7-1-0-0	83	428

TABLE 9. Mechanical arming spread of T-30 and T-2004 units on AR 5.

	Pooled estimate of standard deviation	Amount short of the mean for 1% armed	Amount beyond the mean for 95% armed	Total spread 1% to 95% armed
Arming distance	49 ft	129 ft	91 ft	220 ft

From such pulse test data it is possible to calculate a probability distribution of total arming distances. The results are summarized in Table 10. No pulsing tests performed with other rockets yielded sufficient data for probability distributions.

TABLE 10. Results of pulsing tests of T-30 units on AR 3.5, 1.15-mf firing condenser.

Delay resistor (megohms)	Arming time (sec) 1%	median	95%	Arming distance (ft) 1%	median	95%
0.51	1.09	1.36	1.58	740	1,060	1,310
0.75	1.26	1.53	1.76	940	1,240	1,480

The analytical comparison of the data of Table 10 with engineering prediction is too complex for presentation here. The difficulty of the tests was increased by lack of accurate ballistic data for VT-fuzed rockets, and reference 31 should be consulted for an adequate treatment of the data. Essentially, the analysis showed that there was satisfactory agreement between prediction and observation if it was assumed that one "dumping" cycle occurred in most of the fuzes before complete arming (see Section 3.3.6 for description of dumping).

CALCULATED PERCENTAGE POINTS FOR TOTAL ARMING

It is indicated in the preceding section that minimum safe arming distances can be predicted from data on mechanical arming performance together with the engineering theory of RC arming. In order to make conservative predictions, it is desirable to assume that "dumping" does not occur. Maximum arming distances calculated on this basis are likely to be underestimates. However, since the number of "dumping" cycles that occur is likely to depend considerably on any condition, such as temperature, that affects afterburning, it appears desirable to calculate the maximum arming distance on the same basis as the minimum. Calculated values are given in Table 11 for several values of arming delay resistance. Rocket ballistic tables[38] were used in making estimates for the HVAR. Table 11 is probably most reliable when used in connection with the T-2004, in which "dumping" is less likely to occur. In connection with the T-30, especially on the HVAR, it should be remembered that the actual maximum (or 95 per cent) arming distance is likely to be in excess of tabulated values, on account of the "dumping" phenomenon.

TABLE 11. Mechanical and total arming distances of rocket fuzes, 1.15-mf firing condenser.

Delay resistor (megohms)	Arming distance (ft) 1%	Median	95%
	AR 3.5		
Mech. arming	350	600	740
0.51	740	1,060	1,300
0.75	930	1,240	1,480
1.50	1,460	1,760	1,980
	AR 5.0		
Mech. arming	330	460	550
0.51	450	790	1,020
0.75	650	970	1,200
1.50	1,180	1,470	1,700
	HVAR		
Mech. arming	420	650	810
0.51	940	1,140	1,530
0.75	1,160	1,360	1,760
1.50	1,830	2,080	2,630

TESTS OF SAFETY

Safety tests were conducted by the Navy Bureau of Ordnance at Inyokern[42, 43] to determine the fragmentation effect, in cases of early functioning. In these tests a TDR drone was modified to fire HE-loaded AR 5's, fuzed with T-30 or T-2004 fuzes, wired to fire on mechanical arming. The rockets were fired from under the wings of the drone, when the aircraft reached maximum airspeed in a maximum dive angle of about 10 degrees. The results of 27 rounds, all of which functioned on mechanical arming, showed no hits on the drone. Since these fuzes had no normal RC delay, it was concluded that rearward fragmentation damage to the firing plane was a very remote possibility.

9.3.3 Performance of T-30 Fuzes

Practically all the data on T-30 performance were obtained with pilot production models. Some of the early testing was done with modified bomb fuzes. Two peak amplification frequencies, approximately 100 and 70 c, were tried during pilot production, and there were a number of other variations, including changes in RC delay resistor, generator shaft couplings, and thrust bearings.

Because of difficulties with dispersion in firing the Navy rockets from a fixed launcher at a mock-plane target (see Chapter 8) most of the testing was performed by firing at high angle or from a plane for function on approach to water. The relation between the scores obtained in the two types of tests has already been discussed in Section 9.2.

AFTERBURNING AND EARLY FUNCTIONING[17]

General. Before discussing the performance of the T-30 in the conventional types of tests just mentioned, it is desirable to give some attention to the problem of early functioning and afterburning. A VT fuze on Navy rockets has to be armed at some time subsequent to the main burning time to avoid malfunctioning due to afterburning. This fact puts a serious limitation on the tactical effectiveness of the VT fuze on these vehicles.

Experience with the T-5 Army rocket fuze had shown the importance of afterburning (see Section 9.2). In field tests of developmental models of T-30 on Navy rockets it was noted that there was a great deal of afterburning from the motors, and the poor performance of the fuzes was attributed to this afterburning. These early fuzes had no RC arming delay.

A cooperative investigation between the Navy, Division 3 and Division 4, NDRC, was started at the Naval Ordnance Test Station [NOTS], Inyokern, in order to find means for reducing the effects of afterburning on HVAR.

The Propellant Grain and Its Burning Characteristics. The cruciform grain of Ballistite used in the HVAR has a length of 39.5 in. and an outside diameter of 4.20 to 4.26 in. After ignition the burning is maintained at nearly constant rate by means of inhibitors. The burning progresses until the surface of the grain has decreased so greatly that the resulting pressure will not support the primary burning. A core of unburned Ballistite remains at the end of the main burning. After the main burning, the core continues to receive heat from the motor wall and nozzles; its temperature is raised, and secondary burning is initiated. The secondary burning continues until the core is either consumed or becomes small enough to be ejected through the nozzle.

The rate of secondary burning is so low that negligible contribution is made to the forward thrust of the rocket. The core is, therefore, useless to the rocket and far more useless to the fuze, since afterburning causes malfunctions.

Static Tests in an Airstream. Static tests at Alleghany Ballistics Laboratory and at Inyokern, conducted by placing the rocket in a stream of air to simulate some of the conditions of flight, showed definite correlation of fuze pulses with afterburning. Afterburning of the Ballistite caused pulses which were several times as strong as the pulses necessary to trigger the fuzes.

Since afterburning depends on the presence of the core, it was decided to eliminate a large portion of the core by extruding the Ballistite grain with an axial perforation. The presence of the perforation suggested the possibility of filling the void with some substance which might be beneficial in overcoming the after-

burning. Sand, table salt, hypo, sal soda, borax, alum, and Epsom salts were tried. Empty perforations were also tried. Comparisons of these loadings were made with standard grains. Hypo, alum, and Epsom salts proved to be the best. The others were less effective but superior to standard grains. It may be that evaporation of water of crystallization in some of these materials might cool the gases to such an extent that afterburning would not be started. It was found to be equally effective to place quarter-pound bags of hypo, wrapped in cloth, ahead of the igniter. As a practical measure, hypo may be unsatisfactory, because it melts at 120 F (this temperature could be easily exceeded in motors exposed to summer sun), and even if it did not melt, the crystals would yield water vapor, which would be absorbed by the Ballistite, where it might cause trouble. For these reasons, alum or Epsom salts would be better, because each of these contains as much or more water of crystallization and yet has a lower partial pressure of water vapor. Common salt and sand, which have no water of crystallization, give much better results than standard rounds, but inferior to those containing water of crystallization. The fact that hypo, alum, and Epsom salts, which gave the best performance, are sulfates suggests that the presence of sulfur may be an important factor.

Results with hypo showed no afterburning and no pulses in any of 13 static experiments.

Ground-Launched HVAR Tests. The fuze had performed well on the HVAR, fired statically in the airstream, with hypo in the perforation in the grain. However, when such rounds were fired from a ground launcher, the addition of hypo bags impaired significantly fuze performance in flight. The fact that hypo bags had eliminated the afterburning in the static tests, yet increased the early functioning in the flight tests, is one of the paradoxes in the afterburning program.

The HVAR rockets, modified to have single nozzles in place of standard multiple nozzles, were fired but failed to indicate a significant difference in performance from standard HVAR. It was thought that the single nozzle would permit ejection of the core at the end of primary burning, as is often observed to be true of AR rockets.

Plane Firing with HVAR. The final appraisal of T-30 performance must come from plane launchings, since this type of testing is nearest to tactical conditions. Fuzes must be ready to function after the rocket is at a short yet safe distance from the firing plane. Effectiveness will be limited by the proportion of duds and random functions, the lateness of arming, and rocket dispersion.

The results from rounds fired from a plane in a dive at various ranges indicated an average time delay of 0.3 sec due to dumping of the firing condenser caused by afterburning. This extra time is much shorter than was expected from the static firings and shows that static firings cannot be relied upon to indicate the performance of plane-fired rounds.

The variation in fuze performance under different test conditions is further accentuated by comparing early-function scores of ground-launched and plane-launched rounds. A test at Inyokern of T-30 on standard HVAR, fired at a slant range of 2,500 yd from a plane in a 30-degree dive flying at 200 mph, yielded 5 duds, 58 propers, and 27 earlies (32 per cent early-function score). The early functions centered at 1.85 sec, which is only slightly greater than the arming time. These results may be compared with the data in Table 12 for ground-launched HVAR, which show a 17 per cent early function score.

Conclusions. The main conclusions obtained from the study of malfunctioning of VT fuzes and afterburning of rocket motors are as follows: Many correlations have been made of afterburning and VT fuze malfunctioning, but as yet very little has been definitely proved about the fundamental causes of afterburning. Static experiments, using a 110-fps airstream past the rocket nozzle, correlate the afterburning with pulses on the fuzes and indicate that a large portion of malfunctioning on the HVAR would be due to afterburning. Hypo, which decreased the afterburning in static firings, caused an increase of early functions on ground-launched rounds. On the other hand, standard HVAR rockets launched from a plane produced a larger proportion of early func-

[redacted]

tions. This suggests a real difference in performance, but it is difficult to explain why an increase in the airspeed of a rocket from a supersonic velocity to a higher supersonic velocity would increase the proportion of early functions. Therefore, firing fuzed rockets from airplanes, though a more difficult procedure, seems to be the only reliable procedure to use in any further study of the phenomenon that may be undertaken.

Performance in Firing for Function On Approach to Water

The performance of T-30 fuzes fired from a ground launcher for function on approach to a water surface is summarized in Table 12. The summary for fuzes fired from a plane for function on approach to water is given in Table 13. Burst heights are included as a matter of general interest in Table 13, although they are of secondary significance in connection with the intended air-to-air application of the fuze. Results obtained with fuzes with different amplifier characteristics (indicated by the frequency of maximum gain [PkAF]) are pooled in Table 12, since there was no evidence of any effect of this difference on the scores. Burst heights are affected by PkAF and are, therefore, not given in this table.

It should be noted that the velocity of the light AR 3.5 (AR 3.5 with the special 4-lb shell) is about the same as that of the HVAR, while the regular AR 3.5 and AR 5 are progressively slower (in the order named). According to experienced observers, afterburning is most pronounced with respect to both intensity and duration in the HVAR.

In examining the high-angle test results in Table 12, it will be noted that although the dud scores are a little high, they are not excessively so in comparison with most production model VT fuzes. For equal flight times (quadrant elevations), middle functioning is markedly greater on the HVAR than on the light AR 3.5. A rational explanation is provided by the prolonged afterburning of the HVAR. Early functioning is uniformly about 20 per cent on the high-speed rockets, and significantly less on the regular AR 3.5. The excess on the light AR 3.5 is most plausibly associated with the greater intensity of mechanical vibration of the rocket that is to be expected at the higher speed. If the difference were accounted to electric disturbances caused by the higher generator speed, a still greater excess of early functions might be expected on the HVAR, where afterburning is so prominent.

Since 5 sec may be taken as a maximum useful flight time for plane-to-plane firing, it is reasonable to combine the middle-function scores with the proper-function scores. The data in Table 12 then give rather uniform proper-function scores of 73 to 77 per cent on the high-speed rockets. A reliability of about 75 per cent is thus indicated for rounds well within the radius of action of an airplane target at extreme range.

Table 12. Performance in high-angle firing.

Reference number	Number fired	Per cent P	E	M	D	Quadrant elevation (degrees)
		AR 3.5				
57	252	83	9	2	6	30
		HVAR				
58	122	55	20	22	3	55
		*AR 3.5**				
59	112	64	19	9	8	55
		*AR 3.5**				
60	216	55	21	18	6	70

* AR 3.5 with a special 4-lb shell for testing VT fuzes.

Special comment is needed on the results of plane-to-water firing given in Table 13, and it may as well be admitted at the outset that most of the data would have been omitted had there been anything more reliable to offer for study. The first three lines of data in this table represent results obtained with six missions of eight rounds each. Subsequent high-angle firing, and the test summarized in the last entry in the table, gave a very strong indication that the excessive dud scores were due to the use of Fahnstock clips on the arming wires (some of which were reported broken after these tests). Unfortunately, carrier observations were not made in the initial test, so that it was not possible to localize sharply the source of the trouble. The differences between the first three dud scores may be due to the differences in the

TABLE 13. Performance of T-30 in plane-to-water firing.[64a] Flight time, 4 to 5 seconds.

Number fired	Per cent P	Per cent E	Per cent D	Mean burst height (ft)	Standard error mean (ft)	PkAF (c)
AR 3.5 Dive angle 30-50°; dive speed 235-250 mph						
16	75	0	25	104	5	77
AR 3.5 Dive angle 30-50°; dive speed 235-250 mph*						
16	100	0	0	95	4	77
AR 5.0 Dive angle 30-50°; dive speed 235-250 mph						
16	50	6	44	102	6	77
AR 5.0 Dive angle 40°; dive speed 320 mph						
23	91	9	0	325	17	100

* AR 3.5 with a special 4-lb shell for testing VT fuzes.

initial accelerations of the three rockets. However, the differences cannot be regarded as having much statistical significance in view of the fact that there were only six missions and in view of the likelihood that the arming wire installations were probably fairly uniform for each mission.

If it were not for the possibility that some of the duds were due to the "dumping" phenomenon, one might adjust the dud scores to be equal to the average of the values given in Table 12. However, the only safe conclusion is that there is no inconsistency between the plane-to-water firing results, and the high-angle firing results when due allowance is made for duds caused by the use of Fahnstock clips on arming wires in some of the plane-firing tests.

PERFORMANCE IN FIRING AT A FIXED MOCK-PLANE TARGET

There were a number of mock-plane tests at Blossom Point, using various rockets and variations of fuze design. Many of the tests were made, using modified T-50 fuzes[27] before T-30 models had been constructed. Shortly after a satisfactory design for the T-30 had been developed, emphasis was shifted to the T-2004 for air-to-ground firing; hence, only a small number of rounds were fired against the mock plane with the final design of T-30.

The results of T-30 target tests are given in Table 14. In order to indicate the radius of action there are included the observed impact parameters p of trajectories defined as

p max = distance in feet of the farthest trajectory from the target for target functions.

p min = distance in feet of closest trajectory to the target for any fuze that functioned far beyond the target.

TABLE 14. Performance in firing at a fixed mock-plane target.

Projectile	Number fired	Per cent P	Per cent E	Per cent L	Per cent D	p Max	p Min	PkAF
AR 5.0	20	65	0	30	5	74	72	100
AR 3.5*	20	40	5	50	5	98	70	100
AR 3.5*	20	60	0	20	20	101	101†	76
AR 5.0	20	65	0	20	15	98	89†	78

* AR 3.5 with a special 4-lb shell for testing VT fuzes.
† Two fuzes which passed the target at 33 and 34 ft respectively and later functioned on approach have been omitted from consideration. These were either unusually insensitive or were not armed at the target because of possible dumping of the firing condenser.

Spot charts showing the position and distance of closest approach (impact parameter) of all target and passage functions may be found in reference 29.

Fuzes with amplifiers peaked at 100 c appear to have a radius of action of approximately 70 ft; fuzes with peak frequencies of 77 c show a radius of action of approximately 90 ft. Except for the two rounds which passed the target at 33 and 34 ft, the bulk of the live rounds which passed the target without firing began at 70 or 90 ft respectively. The results for fuzes with trajectories within the radius of action are as follows:

PkAF, 100 c; radius of action, 70 ft

N	P	E	L	D	$\%P$
16	15	0	0	1	94

PkAF, 77 c; radius of action, 90 ft

N	P	E	L	D	$\%P$
29	22	0	3	4	76

The almost complete absence of early functions, shown above, is to be attributed to the short distance from projector to target (1,200 ft).

PERFORMANCE IN PLANE-TO-DRONE FIRING

Firings against a drone were conducted at the Naval Ordnance Test Station at Inyokern. The T-30 fuzes on AR 5.0 and AR 3.5 were

[redacted]

ripple fired from a torpedo bomber [TBM] equipped with four zero-length rails, against a TDR drone.[42] Spotting charge-loaded as well as HE-loaded rounds were used. Precise measurement of burst positions was impossible because of the test conditions. The firing was done from about 375 yd astern of the drone at speeds of 160 knots (pursuit) and 95 knots (target plane). It should be noted that, although the maximum speed and the reflection properties of the drones employed are somewhat different from those of combat planes, the test conditions were much more like those of combat than any other tests performed with this fuze. Results of the Inyokern tests are given in Table 15.

TABLE 15. Performance in plane-to-drone firing.

	AR 3.5 spotting charge	AR 5.0 spotting charge	AR 5.0 HE-loaded
Early (%)	0	5	17
Passage without function (%)	12	34	33
Proper (%)	88	61	50
Number fired	24	61	6
Mean distance of propers from target (ft)	45	48	21

Several drones were destroyed by the HE-loaded rounds. It was obviously impractical to destroy enough drones to obtain a reliable measure of the probability of so doing. The weighted overall mean distance of the proper functions is 46 ft. Since the passage distances could not be measured, the radius of action cannot be calculated by the usual means. However, the conditions of the test were such that the radius of action would be expected to be roughly 50 per cent greater than the mean distance of proper functions. Considering the assumptions involved in estimating the radius of action in this way, the 70-ft value so obtained is in satisfactory agreement with the estimate of 90 ft from the fixed target tests. A comparison of proper function scores cannot be made, since the number of rounds within the radius of action of the drone is unknown.

9.3.4 Performance of T-2004 Fuzes

The T-2004 is designed for use on rockets fired from a plane against targets on land or water. It has, therefore, been possible to test this fuze under the conditions of its tactical use. However, because of the greater convenience, the larger part of the proof testing has been done by firing from a stationary launcher for function on approach to water. Results of experimental high-angle firing tests are summarized in Table 16. Results of experimental plane-to-surface firing tests are summarized in Table 17. Most of the tests in Tables 16 and 17 involved pilot-production models with a number of variations in arming delay resistance, generator shaft couplers, and thrust bearing. Acceptance tests of the production model T-2004 fuzes were conducted on the AR 3.5 according to the procedure outlined in Section 9.8. Results are summarized in Tables 18 and

TABLE 16. Performance in experimental high-angle firing. Target factor: 81.

Reference No.	Approximate flight time (sec)	Number fired	Per cent *P*	Per cent *E*	Per cent *M*	Per cent *D*	Mean burst height (ft)	Standard error mean (ft)
			AR 3.5, quadrant elevation 30°					
61	26	288	92	4	1	3	18	0.4
			AR 5.0, quadrant elevation 30°					
62	18	20	85	0	0	15	19	1.1
			HVAR, quadrant elevation 30°					
63	31	25	64	20	4	12	33	1.9
			AR 3.5, quadrant elevation 70°					
64	47	24	92	4	0	4	19	1.2

[redacted]

20. In all cases where the target factor (reflection coefficient in per cent) is given as 81, the target was a water surface. Acceptance testing was done at Aberdeen (target factor 81) and Jefferson Proving Grounds (target factor 65). Target factors for firing against ground at Dahlgren and Inyokern are unknown.

so rare that the available data are insufficient to give a reliable time distribution. The acceptance test data do show, however, that the incidence of functions from arming up to 5 sec is roughly ten times as great as it is during any later equal period. The 5-sec limit may, therefore, be regarded as a useful one, even though

TABLE 17. Performance in experimental plane-to-surface firing.[43, 64b]

Approximate flight time (sec)	Number fired	Per cent *P*	*E*	*D*	Mean burst height (ft)	Standard error mean (ft)	Target factor
		HVAR, 30° dive, plane speed 320 mph					
2	8	12	0	88	32	...	Land
3	16	63	6	31	64	4.7	81
		4.5" T-87, 30° dive, plane speed 250 mph					
8	20	85	0	15	32	1.2	81
		AR 5.0, 30° dive, plane speed 310-340 mph					
3	40	86	2	12	33	1.4	81
		AR 5.0, 40° dive, plane speed 345 mph					
4	79	94	3	3	27	...	Land

Inspection of the tabulated flight times shows that the time available for middle functioning was very limited in the plane-firing tests, and no such functions were recorded in the tests of Table 17. In several of the tests summarized in this table, there was a very limited opportunity even for early functions. In this connection it should be noted that the 5-sec time limit used in the classification of early functions of the Navy rocket fuzes is a carry-over from the testing of the T-5 Army rocket fuze. Malfunctioning of the T-2004 is

its significance in relation to afterburning is not well defined.

It should be noted that the classification, "late" (functions below 10 ft), used in the acceptance tests, is a carry-over from the acceptance testing of bomb fuzes (see Section 9.4). This classification was not used in the experimental tests in which either the Army or Navy rocket fuzes were fired for function on approach to a ground or water target. The acceptance usage was based on considerations of military utility rather than on the existence of any

TABLE 18. Performance of T-2004 in metal parts acceptance tests.

Lot* group No.	Approximate flight time (sec)	Number fired	Per cent *P*	*E*	*M*	*L*	*D*	Mean burst height (ft)	Standard error mean (ft)	Target factor
			Quadrant elevation 30°							
1	26	817	90	1	1	2	6	32	0.4	81
			30° dive, plane speed 250 mph							
2	7	100	88	2	2	1	7	47	1.8	81
			Quadrant elevation 20°							
3	19	877	95	2	1	0	2	28	0.3	65
			Quadrant elevation 42°							
4	34	87	92	6	0	0	2	17	0.6	65
			20° dive, plane speed 290 mph							
5	6.5	83	98	0	0	0	2	32	0.7	65

* See Table 19 for identification of lots.

[redacted]

discontinuity in the function height distribution (see Section 9.1.3).

Proper functioning performance on the AR 3.5 ranges from 88 to 98 per cent in the tables. Information on performance on the AR 5.0 is limited to pilot production models, and performance is not quite as good, averaging about 90 per cent proper functions. The deficiency is due mainly to the rather high incidence of duds. This may easily be attributable to difficulty with detonator contact spring adjustments. There is evidence of a progressive reduction in dud scores throughout production, as shown in Table 18. This parallels experience with bomb fuze production as shown in Section 9.4.3, where the phenomenon is discussed more fully. There is no known reason why performance should be better on the AR 3.5 than on the AR 5.0, and it is probably quite safe to take the acceptance data as representing the reliability of the fuze on both rockets.

TABLE 19. Composition of lot groups in Table 18.

Lot group No.	Metal parts lots
1	1001–1060 excluding lots ending in the digit 8
2	1008, 1018, 1028, 1038, 1048, 1058
3	1061–1066, 1072A, 1074A, 1075–1097, 1099, 1100–1107, 1109–1117, 1119–1122
4	1067, 1069, 1074
5	1068, 1078, 1088, 1098, 1108

TABLE 20. Performance of T-2004 in ammunition lot acceptance tests. Quadrant elevation: 20° in most cases; target factor: 81; lots: 315–2 through 315–20.

Approximate flight time (sec)	Number fired	Per cent *P*	*E*	*M*	*L*	*D*	Mean burst height (ft)	Standard error mean (ft)
19	177	94	2	1	1	2	32	1.1

Scoring performance on the HVAR is conservatively represented by the data in Table 16, since a short RC arming delay (0.75 megohm, 1.0 mf) was used in the test. The same delay was used in the HVAR tests given in Table 17. These results have little significance except for very short flights.

It is not possible to make a satisfactory comparison of observed with predicted burst heights on account of the absence of reliable terminal ballistic data on VT-fuzed Navy rockets. Approximate calculations indicate that, as in the case of bomb fuze burst heights, there are some inconsistencies in the burst heights recorded for the different test conditions in Table 18. None of the discrepancies is serious, however, and a fuller discussion is unwarranted here.

Particularly interesting data on burst heights were obtained in the Naval Ordnance Test at Inyokern,[43] in which some of the fuzes were fired from a plane in ripple salvo on HE-loaded rounds. Results are summarized graphically in Figures 9 and 10, in which some acceptance data are added for comparison. In the test at Inyokern, all burst heights were measured photographically, and they are probably more accurate than those estimated with the camera obscura in acceptance testing.

There is no systematic evidence of sympathetic functioning of HE-loaded rounds fired in ripple salvo. In general character, the results resemble very closely those obtained in similar tests with the Army rocket fuzes. The main difference is that the T-2004 burst heights are lower (with due allowance for reflection coefficient), since the fuze was designed to have a lower overall sensitivity in order to avoid excessive burst heights.

9.4 BOMB FUZES

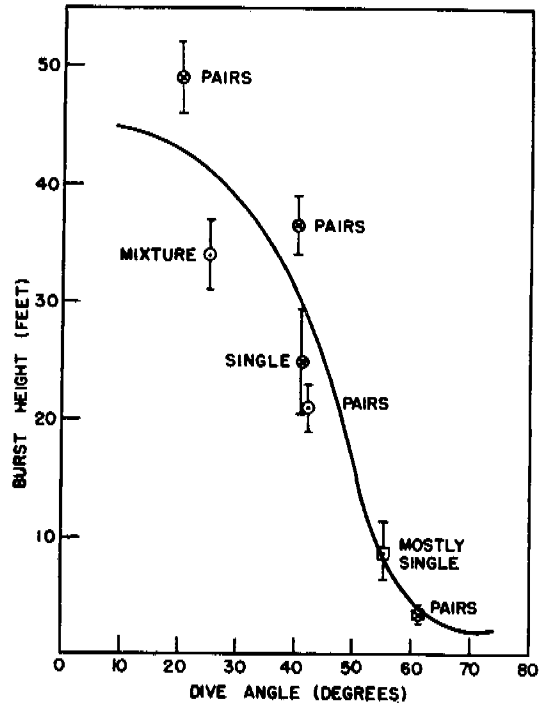
9.4.1 Introduction

This section presents the results of bomb-fuze testing, both experimental and acceptance. Results are based in so far as possible on performance of production model units; only in cases where data from such units are inadequate are they supplemented by those of earlier models.

It will be noted that certain tables in this section are exceedingly brief. Although a much greater amount of testing was done (which

[redacted]

was more or less pertinent to some of the subjects discussed) than is shown in the tables, much has been eliminated in an effort to keep the data free from extraneous factors. For



Code	Range	Explosive
⊙	1,500 yd	Spotting charge
□	2,000 yd	Spotting charge
⊗	1,500 yd	High explosive
⊠	2,000 yd	High explosive

Vertical bar indicates ± one standard error of mean.

FIGURE 9. Burst height as function of dive angle, T-2004 on AR-5 for indicated mode of firing.

example, Table 27 in Section 9.4.3, showing the effect of vehicle on performance, includes data for one type of fuze only, since data on other fuzes were complicated by variations in release altitudes or plane speeds. It is to be understood that the pertinent data that are omitted show satisfactory general agreement with engineering prediction but are unsuitable for analytical purposes.

In the evaluation of performance the following classifications of functions are used:

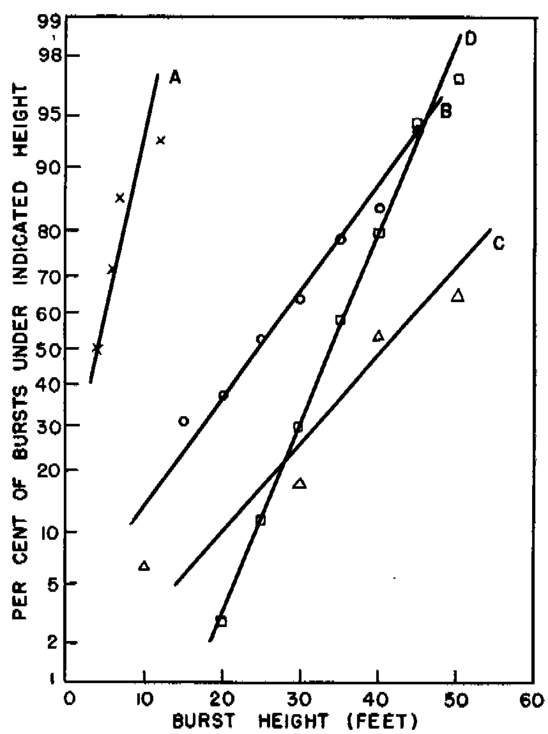
Proper (Pw). A proper function is one occurring because of interaction between the fuze and the target. In acceptance work, definite arbitrary limits on heights were set (see appendix to this chapter). For scoring of experimental rounds a less rigid criterion was used. Functions occurring within about twice to one-third the mean burst height of those definitely "on target" were scored as proper.

Low or Late (L). A low function is one occurring below the lower limit set for proper function.

Early (E). An early function is one occurring too soon to be called proper.

Dud (D). A round in which no function occurs is classified as a dud.

Note that all results are for release in level flight unless specified otherwise.



Code	Dive angle	Speed (mph)	Range (yd)	Proving ground
A	55°-60°	350	1,500-2,000	Inyokern
B	40°	350	1,500-2,000	Inyokern
C	20°-25°	350	1,500-2,000	Inyokern
D	30°	310-340	700-1,700	Dahlgren

FIGURE 10. Cumulative burst height distribution for various dive angles, T-2004 on AR-5.

9.4.2 Safety and Arming

GENERAL REMARKS

A great deal more attention was given to tests of the arming characteristics of bomb fuzes than in the case of other fuzes. The ex-

perimental data on this subject are very voluminous. An exhaustive analysis of arming performance is given in reference 22. The principal results of this analysis are summarized in this section. The basic data on arming performance may be found in detail in reference 65.

The extensive testing on the arming mechanism was primarily due to

1. The compromise between two contradictory objectives. The first objective was to postpone arming as long as possible in order (a) to protect the bombing plane from fragments from bombs exploding upon arming, or (b) to prevent the fuze from operating on other friendly planes in a deep formation. The second objective was to have arming occur as soon as was reasonably safe in order to allow level or dive bombing from low altitudes.

2. The inherent spread in arming values due either to conditions of use or variations in manufacturing tolerances.

The method of operation of the arming mechanism has been described in previous chapters (cf. Chapters 4 and 5). Here we are concerned primarily with the results of tests on the overall mechanism and of tests on the effect of the different parameters which cause variations in arming, i.e., (a) effective pitch of vanes of the windmill, (b) effective airflow around the nose of the bomb, (c) angular rotation of the detonator rotor to arming, and (d) reliability of the detonator contacts and the rotor locking pin.

Pertinent Features of the Arming Mechanism

1. *Air Travel.* The windmill-driven arming mechanism yields air-travel-to-arming for a given bomb and rotor-setting which is roughly independent of altitude of release and plane speed.

Effect of Release Altitude. To within the degree of experimental accuracy necessary for determination of rotor-settings, the air-travel-to-arming has not been found to be affected by the variation in air density between different altitudes of release (3,000 to 20,000 ft). In any event the most precise data are required only for the low-level bomb releases, such as are used for rotor-setting calibration tests; changes caused by higher altitudes are not important on account of the added safety available through use of the delayed arming device. Further consideration of high-altitude releases is given later in this section.

Effect of Plane Speed. Variations in plane speed have somewhat greater effect. Wind tunnel calibrations of vane speed versus wind speed performance of various windmills and turbines indicate a decrease in air travel at higher plane speeds. For the 10-bladed metal vanes and 3-bladed plastic vanes, the effect is less than the normal spread between units released under similar conditions (less than 3 per cent per 100-mph change in plane speed on the average). For the turbine-driven type, increasing the plane speed from 200 to 300 mph appears to decrease air travel by about 10 per cent, while a decrease to 150-mph plane speed results in a 15 per cent increase. It should be remembered, however, that the separation between the bomb and the launching aircraft is less at the higher airspeeds, even with the same air travel for the bomb. For example, after 4,000 ft of air travel, the separation between plane and M-30 test bomb is 2,100 ft at 200-mph release but only 1,250 ft at 300-mph release. The last fact is more important from the point of view of safety than the relatively smaller change in air-travel-to-arming.

Effect of Bomb. The air-travel-to-arming for all fuze types is greatly modified by the aerodynamic characteristics of the bomb. The airflow about the nose of the vehicle affects the rotational speed of the windmill or turbine to a much greater extent than it influences the trajectory of the bomb. For example, the turbine-type fuzes (T-82) on a large bomb (M-66) may travel more than twice the distance to arming than on the small test bomb (M-30) with the same rotor setting. This fact is quite consistent with safety requirements. Data on air travel ratios between various bombs is given in a later part of this section, under "Arming Performance of Typical Fuzes."

2. *Operation and Use; Rotor Setting Methods.* Setting of the rotors is accomplished by either of two methods: (a) counting of vane revolutions from the electric arming position or (b)

[redacted]

measuring the angle of the slot in the slow-speed shaft from the mechanical arming position. In the first method the vanes are rotated backward from the electric arming position by an electric motor attached to a mechanical counter. Electric continuity provides an indication of the electric arming position. In the second method, the angle between the slot in the slow-speed shaft and a reference point on the rotor housing collar is set according to the indications of a mechanical gauge. Knowledge of the reduction ratio of the gear train and the angular separation between the slot in the slow-speed shaft and the reference point on the housing collar, when the rotor is in the electric arming position, allows conversion of setting specifications from one system to another. Comparative merits of the two methods are discussed in reference 22.

Methods of Release; Low Altitudes. Fuzes are supplied with an arming pin which blocks rotation of the vanes. The arming pin is held in place (while in the bomb bay) by the free end of an arming wire, the other end of which is fastened to the plane. When the bomb is dropped, the arming wire pulls out of the arming pin, releasing it and permitting the vanes to rotate in the wind stream.

Methods of Release; High Altitudes; Use of Arming Delay Device T-2. The arming mechanism of the fuze proper is not generally set to give air-travel-to-arming greater than about 4,000 to 5,000 ft. When air travel in excess of this is desired, a supplementary arming delay device (T-2) is employed (see Figure 1, Chapter 4). This device prevents expulsion of the vane blocking pin until the bomb has fallen through a predetermined distance along its trajectory. The device may be adjusted manually to yield up to 20,000 ft of additional air-travel-to-arming for the fuze.

Settings for Given MinSAT

Statistical Method. In the production of VT bomb fuzes, the determination of rotor settings has been based on the requirement of a specified *minimum safe air-travel-to-arming* [MinSAT] on the smallest bomb on which the fuze is to be used (M-30 in most cases). *This MinSAT may be defined ideally as a lower limit, below which no fuze will ever become armed.* Owing to variations within the range of currently permissible manufacturing tolerances, the air-travel-to-arming for an individual fuze from a given lot may be found to differ from the mean value for the lot by as much as several hundred feet when dropped in the field. It is not practicable, therefore, to set the fuze rotors so as to yield a mean air travel equal to the specified MinSAT, since in that case about half of the fuzes would become armed before traveling the MinSAT. Accordingly, a safety factor is introduced in the form of a tolerance distance to be added to the MinSAT in order to obtain the mean air travel for which the rotors should be set.

To establish the proper value for this tolerance distance, it is necessary to determine the relative frequency of occurrence of units with air travel short of the mean by any given amount. The functional form of this distribution of frequency may be developed mathematically from the assumption that a given deviation from the mean air travel is caused by the random superposition of a great many small independent deviations, each presumably due to a variation of some physical characteristic of the fuze from its average value for the lot. The frequency distribution resulting from these assumptions is the normal error law, which the observations appear to follow quite closely. This law does not, however, define an absolute lower limit for the possible values of air travel. In practice, therefore, the ideal definition of MinSAT given above must be modified to denote a limit below which only a certain negligibly small percentage of the units become armed. With sufficiently large test samples, the location of this limit for any given production lot could be determined by a count of the units of extreme short air travel. Practically, however, such a procedure is inapplicable on account of the magnitude of the test samples that would be required. It is evident that in small test samples, units with extreme characteristics will seldom appear, and their scarcity will make direct count estimates of their probable frequency very unreliable. Such extreme units, however, are to be expected in much greater numbers in the much larger produc-

tion lots. It becomes necessary, then, to infer their presence through an application of frequency distribution theory to observations on the more numerous, more nearly typical units of which the small test samples are mainly composed.

This is accomplished by determining the appropriate numerical values of the dispersion parameter for the normal frequency distribution (the standard deviation) from field test observations of samples of the various fuze types. The use of these values for extrapolation from the mean air travel, according to the theoretical distribution formula, then gives the air travel limit which only the selected negligible percentage of units will fail to exceed before arming takes place. The MinSAT is estimated from the mean air travel by the following procedure.

Consider the mean air travel as the sum of three quantities: (1) the MinSAT, (2) a multiple of the standard deviation in air travel for the given fuze type, and (3) a supplementary allowance.

1. The MinSAT is understood for this purpose to mean a fixed lower limit of air travel, below which only a negligibly small percentage of nondefective fuzes have a chance of arming.

2. The multiple of the standard deviation represents a minimum permissible difference between the MinSAT and the mean air travel for the given lot corresponding to the adopted rotor setting. The selection of the multiple chosen is based on the condition that on the average, only 1 per cent of the individuals in a normally distributed population will deviate from the mean for the entire group by more than this multiple of their standard deviation.

3. The supplementary allowance is included principally to account for probable differences between the mean air travel for the given lot corresponding to the adopted rotor setting and the mean air travel for the lot from which the test sample was drawn which determined the adopted rotor setting. This type of difference may be thought to originate from sources of variation which were not operating during the limited range of tests used for deriving the statistical parameters. Experience confirms the probable existence of such factors. To evaluate the exact nature of such long-term production variations (which have the effect of increasing the expectation of large deviations) would require a program of more extended testing and wider scope than present practice includes. Continued need for the use of a supplementary safety allowance is indicated by the large deviations from the nominal test release conditions which are likely to occur in actual service use. A liberal margin of safety (200 ft on the average) is generally allowed to compensate for all of these effects.

The air travel limits between which certain specified percentages of fuzes may be expected to become armed are given in Table 21.

TABLE 21. Air travel limits (ft).

Standard deviation of air travel (ft)	100	150	200	250
MinSAT	3,600	3,600	3,600	3,600
Mean air travel (50% armed)	4,030	4,145	4,260	4,375
95½% armed	4,200	4,400	4,600	4,800
Range: MinSAT to 95½% armed	600	800	1,000	1,200

Estimates for other values of standard deviation of air travel may be made by interpolation in the table or by use of the formulas:

Range (MinSAT to 95½ per cent armed) = 200 ft + 4.0 $\times$ (standard deviation of air travel).

MinSAT to mean air travel = 200 ft + 2.3 $\times$ (standard deviation of air travel).

Mean air travel to 95½ per cent armed = 1.7 $\times$ (standard deviation of air travel).

For other values of MinSAT and for any vehicle, the standard deviation of air travel may be taken as approximately proportional to the mean air travel.

Proving Ground Check. Proving ground tests, conducted for purposes of production quality control, are intended as an overall check on arming performance under conditions simulating Service use as closely as possible. Specifications for loading acceptance tests for VT bomb fuzes (phase 1, see Section 9.8) provide that all of a sample of fuzes from a given lot dropped under certain plane speed and altitude conditions

(which correspond to an air travel to ground less than the rated MinSAT by certain tolerance amounts) must fail to function if the lot is to pass. Inspection criteria of this nature are indispensable for effectively guarding against occurrence of defective units. Defective units are defined here as those subject to essentially unpredictable types of variation in air-travel-to-arming such as are caused by nonrandom elements not covered in the overall method of analysis developed earlier in this section. Examples of such exception factors are: (1) an improper choice of rotor setting, (2) a blunder in setting the rotor, or (3) the sudden appearance of some previously unencountered type of defect in a mechanical part. Frequency distribution sampling theory, which presupposes a considerable degree of homogeneity in manufacturing production, is inapplicable to the prediction of such sources of error.

The sampling technique employed for acceptance testing depends simply upon the direct enumeration of infrequently occurring types, and, like all tests of this nature, provides little information on the probability of occurrence of similar rare types in other samples from similarly composed lots. This property, as already noted, is inherent in tests of this sort. It is an unavoidable consequence of the limitation imposed by the test design upon the number of observable specimens with the characteristic about which information is sought. Furthermore, with the usual acceptance test procedure, the minimum permissible air travel that may be observed for a unit (before rejecting the lot containing it) is not in practice rigidly fixed. Instead, the air travel limit defining a prematurely arming unit during any particular test may lie anywhere inside the range extending from the MinSAT distance to a point 350 ft in advance of it. This situation arises principally from the difficulty of maintaining a very stringent control over proving ground testing conditions. In addition, the actual air travel measures (based on observations of time of flight or altitude of release) appear to be generally subject to large random errors, much greater than the variations which experimental field tests show may be properly attributed to the fuses themselves. It must be concluded, then, that while the acceptance tests are invaluable in screening out defective or improperly adjusted units, the data provide little information on the relative number of nondefective units expected to exhibit any particular air travel to arming. In consequence, the acceptance test rejection record is not to be considered as a rigorous check on the accuracy of the specific predictions derivable from the MinSAT control theory presented in Section 9.4.2. Percentages of acceptances and rejections on the basis of air travel performance are given in summary form in Table 22.

Arming Performance of Typical Fuzes

Mean Air Travel versus Rotor Setting. The rotor setting corresponding to a given mean air travel for a particular fuze type is determined by dropping a small sample of units from the production lot. The units are wired to fire a small explosive charge upon electric arming, which is thus made visible from the ground. Observation of the arming time and plane speed, combined with a knowledge of the ballistic properties of the bomb, permit calculation of the air travel to arming for each unit. From these data, an estimate of the air travel per vane revolution under the given conditions is obtained, from which the rotor setting appropriate to a specified mean air travel may be deduced. A description of the field testing procedures is given in Section 8.2.

The rotor calibration test procedure in practice is beset by several difficulties. First, variations in production standards between lots, which cannot be detected by calibration tests conducted on units all from the same lot, may introduce large apparent errors in the choice of rotor setting, revealed only when the units are subjected to the acceptance testing. This situation necessitates the addition of the 200-ft supplemental safety allowance discussed in Section 9.4.2 to all air travel settings. In addition, the large variation of aerodynamic pitch (air travel per revolution) with wind speed for certain types may, if neglected, lead to serious errors in rotor setting estimates deduced for an air travel different from that for which the units were set during the calibration test. Wind tunnel observation of windmill speed at con-

[redacted]

trolled wind speeds appears to be the only satisfactory solution for this problem.

Typical rotor settings adopted for various fuse models may be found in data sheets in Chapter 5. Approximate rotor settings may be computed from the values of the air travel per revolution observed for various vane types in the wind tunnel. Some results, corresponding to an air travel of about 4,000 ft, are given in Table 23. With bombs other than the one on which the calibration test was conducted, allowance must be made for the effect of the vehicle upon the vane speed and consequent air travel to arming. The approximate relative air travel for various type fuzes with the same rotor setting on different bombs is listed in Table 24.

Spread in Air Travel. Determination of the mean air travel for which the rotors should be set in order to conform with a specified MinSAT requires a knowledge of the standard deviation in air travel to be expected in Service use of the fuze type (Section 9.4.2). Data useful for estimating this quantity are provided by field tests such as are used for rotor setting calibration. Further information may be derived from analysis of wind-tunnel fuze performance in combination with certain other laboratory measurements. Both methods provide mutually consistent independent estimates of air travel spread for the various fuze types. The two procedures supplement each other, i.e., field testing duplicates Service use conditions more directly while wind-tunnel test results are less affected by experimental error. Comparative merits of various test methods for

TABLE 22. Acceptance (safety) test performance, phase 1. (A "safe" unit should fail to function.)

Mfr.	MinSAT (ft)	Approx. air travel to ground* (ft)	No. of units tested	No. of functions observed	Percentage of functions (failures)	Approx. tolerance* (MinSAT minus air travel to ground) (ft)
Emerson	3,600	3,500	370	2	½	+100
	3,600	3,000	80	0	0	+600
	3,100	3,300	35	3	9	—200
	3,100	2,900	120	3	2½	+200
	2,600	2,300	20	0	0	+300
	2,000	1,800	10	0	0	+200
Zenith	4,500	4,000	55	3	5	+500
	3,600	3,600	330	3	1	0
Philco	3,600	3,500	315	12	4	+100
	3,100	3,100	100	6	6	0
	2,000	1,900	83	0	0	+100
GE	2,000	1,900	100	2	2	+100
Simplex	3,600	3,500	101	3	3	+100
	3,100	3,100	20	0	0	0
All combined	....	....	1,739	37	2	+100

* The air travel to ground (and tolerance distance) may be in error by several hundred feet.

TABLE 23. Average values of air travel per vane revolution on M-30 bomb in wind tunnel (230-250 mph wind speed).

Fuze and vane type	Air travel (ft) per vane revolution
6-in. Bakelite vane, bar type	1.20
6-in. aluminum vane, bar type	1.32
9-in. Bakelite vane, medium antenna ring	1.32
55° metal, thin antenna ring	1.82
Turbine, bar type	1.47

TABLE 24. Relative air travel on various bombs from field and wind tunnel data.

Fuze type	Bomb type M-30	M-81	M-64	M-65	M-66	M-56	Standard deviation of ratios
Ring and bar types, plastic and metal vanes	1.00	1.02	1.15	1.32	1.58	1.48	±0.02
Bar type, turbine vane	1.00	1.02	1.24	1.48	2.32	1.87	±0.03

determining air travel spread and application of observational data to their calculation are discussed in reference 22, in which numerical examples of air travel spread for various fuze types are given. A few typical examples for late production models (when set for 4,000-ft mean air travel) follow.

Manufacturer	Type	Standard deviation (16% limit) (ft)	Tolerance deviation (1% limit) (ft)
Emerson	T-90	150	350
Zenith	T-51-E1	150	350
General Electric	T-89	175	410
Philco	T-89	230	540
Westinghouse	T-82	250	580

Examples of frequency distributions of the deviations from mean air travel to be expected of individual units may be found in reference 28. Comparisons with the theoretical normal frequency law show sufficiently good agreement between the observed and theoretical distributions to justify use of the normal law in calculating MinSAT tolerances (Section 9.4.2). An example of such a comparison is given in Figure 11.

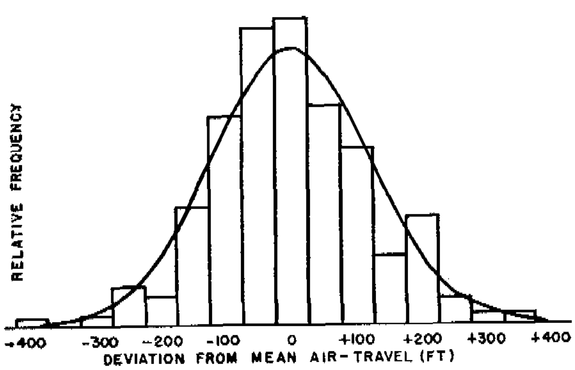


FIGURE 11. Distribution of deviations in air travel to arming for bomb fuzes and corresponding normal distribution fitted to data.

Factors Affecting Consistency of Air Travel Performance. A brief discussion has already been given both of the principal fuze characteristics designed to produce constant air-travel-to-arming under a variety of field conditions and of the extent to which this requirement is found to be fulfilled in practice. There remain still to be considered the observed lack of constancy of air travel performance under *constant* field conditions and the principal factors causing these accidental differences between units of similar design. A comprehensive study of this phase of air travel performance, based largely on wind-tunnel observation, is contained in reference 22.

1. *Vane speed variations.* Differences in air-travel-to-arming between fuzes set to perform identically under the same conditions are accounted for principally by differences in windmill or turbine speed. Variations in construction of the detonator contacts, which cause inadvertent differences in rotor setting under some circumstances, are secondary in importance. The standard deviation in vane speed between units is found to be a certain fixed percentage of the vane speed which is a characteristic of the unit type (model and manufacturer) and is virtually unaffected by changes of vehicle or plane speed. This relationship leads to an approximate proportionality between spread in air travel and mean air travel.

The exact mechanical components of the generator vane and shaft system in which lack of uniformity in manufacture is most effective in producing the observed spreads in vane speed have not been completely identified. Measures of generator shaft torques and of dimensions of certain external mechanical features of the fuzes have thus far accounted for only a negligible portion of the entire observed spread in air travel.

The later revised production models of Emerson and Zenith show a great reduction in random variations in vane speed between units. In wind tunnel tests, these types performed with vane speed standard deviations (and partial air travel standard deviations thereby induced) of about $1\frac{1}{2}$ per cent. Under the same conditions, regular production models by the same manufacturers exhibited almost twice this spread, while variation in other manufacturers' models ranged up to three or four times as much.

2. *Rotor setting errors.* The next most important factor in causing spread in air travel is a lack of uniformity in detonator contact spring construction which leads to random setting errors in rotor-shaft arming angles. This circumstance introduces an increase in the stand-

ard deviation of air travel over that due to vane-speed variation ranging from about 15 to 30 ft. Errors in the actual gauging of the shaft angles contribute only a minor portion of this quantity.

3. *Testing errors.* Another important consideration is the experimental field test observational error, which is responsible for a further (apparent) increase in standard deviation of air travel amounting to from 10 to 30 ft, the effect being the greater for the better models and shorter air travels. The last-mentioned source of variation does not exist in actual operational use. It may be entirely eliminated by conducting the tests on the units in a wind tunnel, without danger of thereby introducing any new or more undesirable sources of error.

9.4.3 Ring-Type Fuzes

Performance under Acceptance Test Conditions

General Remarks. The analysis of performance of fuzes under acceptance test conditions, which provides the field performance data given in Section 5.5, is based on the metal parts acceptance tests. These tests were carried out on a much larger scale and under conditions much more like combat conditions than were the tests of the completely loaded fuzes, i.e., the ammunition lots (see Section 9.3.1 for definitions of metal parts and ammunition acceptance tests). Where the metal parts tests show significant variations in performance it would be possible, theoretically, to make some allowance for these variations in predicting the performance of the ammunition lots. However, the composition of ammunition lots is highly variable. The lot size ranges from a few hundred to several thousand fuzes, and a lot may contain from one to nearly a dozen metal parts lots, or fractions thereof, widely spread with respect to time of production. Furthermore, the loading of the fuzes is known to have introduced factors in one or two cases that were absent in the metal parts testing. Therefore, although the properties of the ammunition in its final form are of primary practical interest, it is not feasible to attempt a quantitative prediction of the effect of variations observed in metal parts testing. For this reason, and because most of the statistically significant variations are not of much practical importance, the data have not been analyzed as exhaustively as would be possible.

In calculating the scores from acceptance test data, the scores obtained with rejected lots are included, since what is required is an estimate of the quality of the product. As with most sampling procedures, rejections were almost entirely the result of random sampling fluctuations, and elimination of the reject scores would yield an overestimation of the quality of the fuzes.

For the sake of simplicity, the Army Ordnance designations for the complete fuzes are used in discussing the performance of the metal parts assemblies, although strictly speaking the Signal Corps system of AN/CPQ designations should be used (see Section 5.5).

Conditions for Acceptance. The procedure for conducting metal parts acceptance tests is summarized as appendix material to this chapter in Section 9.8. The following test conditions hold except where deviations are noted:

Nominal altitude of release: 10,000 ft.
Nominal true airspeed at release: 200 mph.
Test vehicle
 For Brown carrier fuzes:
  M-81 (260-lb) fragmentation bomb or
  M-88 (220-lb) fragmentation bomb.
 For White carrier fuzes:
  M-64 (500-lb) general purpose [GP] bomb.

A double sampling formula was used with the proper functioning requirements stipulated so that a negligible fraction of the metal parts lots would be rejected as long as the manufacturing quality was above an 80 per cent proper-functioning level.[2, 44]

Summary of Data for Various Groups of Lots. In Table 25 there is given the average score and function height for each of several groups of metal parts lots of each of the fuzes. The lot group number (first column) is used for reference purposes in the discussion, and to identify the metal parts lots to which the data apply, with the aid of auxiliary Table 26.

For the most part, the reason for the grouping of the lots is apparent, namely, differences in plane speed, or target factor. The target factor (second column) is the reflection coefficient of the terrain expressed as a percentage. It is to be understood that the target factor is approximately 81 (water surface at Aberdeen Proving Ground) unless otherwise stated (other numerical values apply to Jefferson Proving Ground). The reflection coefficient of ice depends upon a number of conditions which were not recorded in detail for these tests.

Where it is not apparent in the table, the reason for the grouping is given in the discussion of the performance of the fuzes.

Effect of Test Conditions on Performance. There is no reason to anticipate any perceptible difference in scores on account of a 40-mph difference in plane speed, and an inspection of Table 25 shows no consistent indication of such a difference.

With the rather wide limits of burst height that were used in the classification of proper functions, no perceptible effect of target factor

TABLE 25. Metal parts acceptance test results.

Lot group No.	Target factor	Number units tested	Per cent score P	L	E	D	Mean burst height (ft)	Standard error mean (ft)
			Brown carrier fuzes T-50-E1 and T-89 (Philco)					
1		542	79	0	15	6	34	0.7
2	Ice	226	83	0	14	3	32	1.0
3	65	76	90	0	9	1	37	2.0
			T-50-E1 (Philco-Simplex)					
4		387	85	0	11	4	37	0.9
5	Ice	47	81	2	17	0	32	2.2
			T-91 (Philco)					
6		42	76	0	26	0	44	3.6
7		204	83	1	11	5	29	0.4
8	65	680	89	0	10	1	39	0.6
9*	65	37	78	0	20	2	36	1.9
			T-91 (GE)					
10		499	80	0	12	8	41	0.9
11	65	53	89	0	4	7	43	1.7
12*	65	259	89	0	6	5	55	1.2
13*	60	106	87	0	10	3	55	1.9
			M-168 (T-91-E1) (Emerson)					
14*	65	289	93	0	6	1	59	1.2
15*	55	170	92	0	8	0	55	1.3
			White carrier fuzes T-50-E4 (Emerson)					
16		370	80	1	17	2	35	0.9
17		680	75	2	17	6	45	1.0
18		279	82	1	14	3	34	1.1
19	Ice	72	71	0	28	1	32	3.0
20		736	75	1	22	2	38	0.8
21*	65	16	82	0	18	0	58	4.7
			T-92 (Emerson)					
22		1,000	57	1	34	8	33	0.7
23*	65	34	59	0	29	12	48	4.0
			T-92-E1 (Emerson)					
24	65	22	95	0	0	5	39	3.1
25*	65	63	75	0	24	1	48	2.3
26		17	76	0	18	6	39	4.8

* 240 mph nominal true airspeed at release.

on score would be anticipated, and none is observed in the table.

These conditions (plane speed and target factor) are therefore disregarded in estimating the overall score for each fuze.

TABLE 26. Identification of lot group numbers listed in Table 25. (Duplication in lot number indicates part of the lot was tested under conditions of the particular group number.)

Lot group No.	Composed of metal parts lots
1	CPR 43 through 59, 62 through 79, 102, 104, 106
2	CPR 80 through 101
3	CPR 108, 110, 112, 114, 116, 118, 140
4	CPR 1S through 23S, 25S, 29S, 30S
5	CPR 24S, 26S, 27S, 28S
6	CPR 103, 105, 111
7	CPR 166 through 177
8	CPR 107, 109, 113, 115, 117, 119, 120 through 139, 141 through 155, 157 through 165
9	CPR 178 through 180
10	CG 1 through 23
11	CG 24, 25, 27, 31
12	CG 27 through 39, 41, 44, 45
13	CG 40, 42, 43, 45 through 48
14	CEX 3001 through 3014, 3019, 3021, 3022
15	CEX 3015, 3018, 3020, 3023 through 3027
16	CEX 1 through 19, 21
17	CEX 20, 22 through 50
18	CEX 51 through 74
19	CEX 75 through 80
20	CEX 81 through 84, 86 through 104, 106 through 109, 112, 113, 114, 116, 117, 118, 120, 121, 122, 124, 125, 126, and all even numbered lots through 144, 148
21	CEX 146
22	CEX 105, 110, 111, 115, 119, 123, 127, and all odd numbered lots through 195, 201
23	CEX 205, 207
24	CEX 178, 184
25	CEX 182, 184, 176, 178, 180
26	CEX 174

In considering the mean burst heights, the situation is different. Inspection of the predicted isoburst height charts (Section 5.5) indicates that increasing the plane speed from 200 to 240 mph should increase the burst height by something like 10 ft. The theory of operation of the fuzes indicates that a reduction in reflection coefficient from 0.81 to 0.65 should reduce the burst height by 10 to 20 per cent or by something like 5 ft for these data. Such differences are large in comparison with many of the tabulated standard errors of mean burst heights, and one might therefore hope to obtain a good check on the predictions from these data. Unfortunately, there are present in the data certain variations in burst height that cannot be accounted for quantitatively. Attention is called to specific cases presently. At this point it is sufficient to remark that these variations are of a magnitude similar to the predicted differences just mentioned. Therefore no precise check on the theory from these data is possible.

In view of the presence of uncontrolled factors in the data, it is very desirable to estimate the burst height performance from all of the data rather than from selected groups. If the effect of reflection coefficient (other than that of ice) is tested by determining burst-height ratios between lot groups for which all other conditions are presumably equal, and these ratios are weighted in accordance with the amount of data and averaged, it appears that on the whole the effect of target factor (other than ice) is nil. This same procedure indicates that the average target factor of ice, as it affected these tests, is about 92, a result which agrees with an unpublished investigation of this matter. The general conclusion is that some uncontrolled factors are present in the data that give burst heights at Jefferson Proving Ground that appear to be higher than would be expected from the Aberdeen data. This factor might be a difference in the systematic components of the errors in burst-height measurement at the two locations. In order to be conservative in combining data to obtain overall average burst heights for each fuze, the effect of target factor (other than ice) is neglected.

A like analysis shows that the overall average effect of the 40-mph increase in plane speed is to add about 7 ft to the mean burst heights. This value is in reasonable agreement with engineering prediction and it is used in reducing all lot group mean burst heights to a 200-mph basis before calculating average performance for each fuze type, although to be strictly correct a slightly different correction should be made for each fuze type.

Performance of T-50-E1 and T-89. The first six lots of Philco production were tuned on a load equivalent to the M-64 bomb and gave

fairly satisfactory performance on this bomb, although an excessive number of duds was observed. The main cause for the duds had been found in the type-approval test to lie in faulty detonator contact springs. When these lots were tested on the M-81 bomb, a very large number of early functions was observed and production was halted temporarily. Specifications were changed to require laboratory testing on a load equivalent to the M-30 bomb, and the amplifier was changed from the No. 8 to the No. 10 type, which became standard for the T-50-E1.

Acceptance testing was resumed with the M-81 as a standard vehicle, but the dud performance remained poor through lot 42. Omitting retest scores (which would throw undue weight on exceptionally poor lots), the overall performance on M-81 for this series was

	Per cent				Lots
N	*P*	*L*	*E*	*D*	
491	66	0	15	19	8–42
102	80	0	12	8	24, 27, 33, 35, 37, 42 (reworked lots)

The score for the six lots that failed the retest and were subsequently reworked showed a significant but not entirely satisfactory reduction in the occurrence of duds. The lots that were not reworked were, for the most part, loaded into ammunition lots through *PA* — 180 — 15; reworked lots were loaded later.

The performance of the balance of the T-50-E1 and T-89 production is given in Table 25, items 1 through 5. There are no markedly significant differences in these scores, which give an average of

Proper	83 per cent
Late	0 per cent
Early	13 per cent
Dud	4 per cent
Number tested, 1,278	
Mean burst height, 35 ft	

The burst height of the Simplex product is slightly higher than that of Philco but the difference is of little practical importance. The overall average burst height over Aberdeen water is 35 ft.

Performance of T-91. The scores of the various lot groups of both Philco and General Electric Company [GE] production show reasonable uniformity and give the following pooled estimates.

Per cent	Philco	GE	Both
Proper	87	84	86
Late	0	0	0
Early	11	10	10
Dud	2	6	4
Number	963	917	1,880

In early GE production some difficulty with detonator contact springs caused a relatively large number of duds, but the situation was not serious enough to warrant special discussion as in the case of early T-50-E1 production. The Philco T-91 fuzes appear to have benefited from the special attention that had to be given to this problem in the earlier model. No T-91 metal parts production lots were rejected.

There is a rather large difference (15 ft) between the mean burst heights of lot groups 6 and 7, which cannot be explained by any difference between the characteristics of the lots as measured in the laboratory. The only recorded difference in test conditions that might be pertinent is in the test vehicle; group 6 was tested on the M-81 and group 7 on the M-88 bomb. However, there is no known difference between the properties of these bombs that is large enough to account for so large a difference in burst heights. The observed difference is probably due to a chance combination of factors, no one of which is alone sufficient to account for the difference in heights. Group 7 appears to be more inconsistent than group 6 with the other groups, 8 and 9, of Philco T-91, but there is no reason to reject it from the overall estimate of burst heights:

Product	Mean burst height (ft)
T-91 (Philco)	37
T-91 (GE)	44
T-91 (both)	40

The higher burst height of the GE fuzes may be due in part to greater r-f sensitivity (18 as compared with 16 v for Philco), but the unaccountably low burst height of Philco group 7 makes a fair comparison impossible.

Performance of M-168 (T-91-E1). This was a late model fuze, and no more need be said here about its performance other than that it

[redacted]

leaves little to be desired. Overall performance (lot groups 14 and 15) is as follows.

Proper	92 per cent
Late	0 per cent
Early	7 per cent
Dud	1 per cent

Number tested, 459
Mean burst height, 50 ft

Performance of T-50-E4 and T-90. The scores obtained with the various lot groups (16 through 21) in this series are fairly uniform. The lower dud scores appearing in later production are probably due mainly to improvements in detonator contact springs. The excess in early functioning of group 20 as compared with groups 16 and 17 may be due in part to factory rejected and reworked assemblies from T-92 production that were absorbed into T-90 production. Excess earlies in group 19 are not so significant because this is a relatively small group. The variations in early and dud scores happen to be of a compensating nature, so that the proper function scores are quite uniform.

Proper	77 per cent
Late	1 per cent
Early	19 per cent
Dud	3 per cent

Number tested, 2,153

Of the approximately 130 metal parts lots of these fuzes, only 3 per cent were rejected.

As in the case of Philco T-91, there appears with these fuzes a difference between mean burst heights of lot groups that cannot be accounted for quantitatively. The difference is about 10 ft (see groups 16, 17, and 18). There was an upward trend in carrier frequency, to the extent of about 1 mc through part of the production represented by groups 16 and 17, but both theory and correlation tests using field data indicate that this could account for no more than 2.5 ft. As in the case of T-91, the difference is probably due to a combination of factors, and no rejections are desirable in estimating the overall average burst height, which is 39 ft.

Performance of T-92 and T-92-E1. The T-92 is the only production fuze that exhibited generally unsatisfactory *scoring* performance. The initial performance did not appear to be too bad, and it is suspected that a certain change in the fins of the test bombs (see "Effect of Release Conditions" in this section) may have had something to do with the deterioration in performance. This does not appear to provide a full explanation; a more basic explanation concerns an unusual dependence (at White frequency on the M-64) on the electric resistance between the bomb and its fin (see Section 2.13.2). The broader pass band of the T-92 amplifier made the effect more critical than in the T-50-E4. Quality of parts and workmanship were apparently not at fault. Overall performance was as follows:

Proper	57 per cent
Late	1 per cent
Early	34 per cent
Dud	8 per cent

Number tested, 1,034
Mean burst height, 33 ft

Of the 45 metal parts lots produced of the T-92, over 60 per cent were rejected.

Only a few lots of the T-92-E1 were produced before the end of hostilities. Overall performance was as follows:

Proper	79 per cent
Late	0 per cent
Early	18 per cent
Dud	3 per cent

Number tested, 102
Mean burst height, 40 ft

Burst Height Distribution Characteristics. For a given type of fuze the spread in burst heights increases approximately in proportion to the mean burst height when the latter is increased by a change in such factors as reflection coefficient, altitude of release or plane speed. The evidence on this subject is summarized in "Burst Heights under Other Conditions" later in this section.

The general character of the distribution of bursts obtained under supposedly constant testing conditions is shown for three fuzes in Figures 12, 13, and 14. The lot group numbers of Table 25 are given to identify the sources of data. The largest lot groups are used, without regard to target factor. It will be noted that the distributions are much the same in general character for all three fuzes. For some purposes the cumulative distribution curves (Figures 15, 16, and 17) are more useful. For practical purposes, these distributions may be

assumed to be linear when the cumulative percentage is plotted on a probability scale and the burst height on a logarithmic scale. On

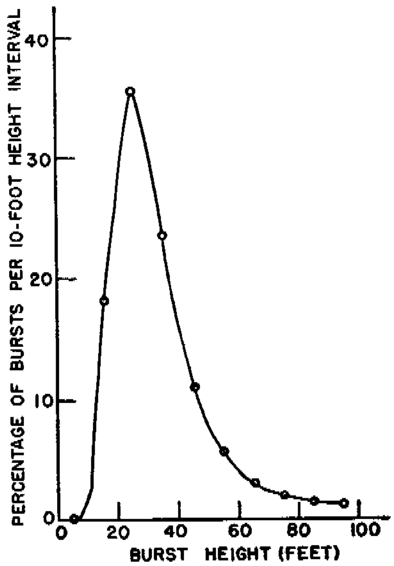


FIGURE 12. Distribution of burst heights of Philco T-50-E1 fuzes over water (lot group 1).

account of the approximately constant proportionality between the spread and the mean burst height, this type of distribution curve is

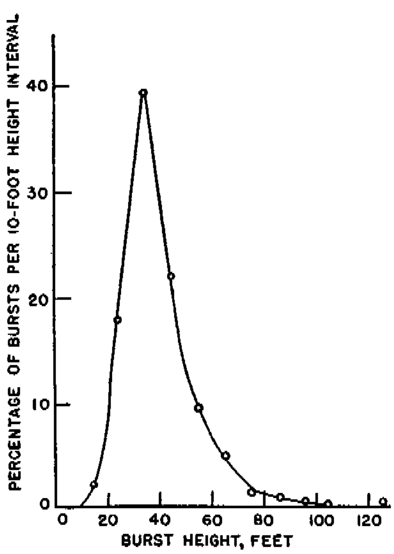


FIGURE 13. Distribution of burst heights of Philco T-91 fuzes over land (lot group 8).

simply displaced without change in slope when conditions alter the mean burst height. For a detailed study of distribution characteristics, see reference 35.

Summary. The overall estimates of performance derived above are summarized in Table 27 for those fuzes that gave reasonably uni-

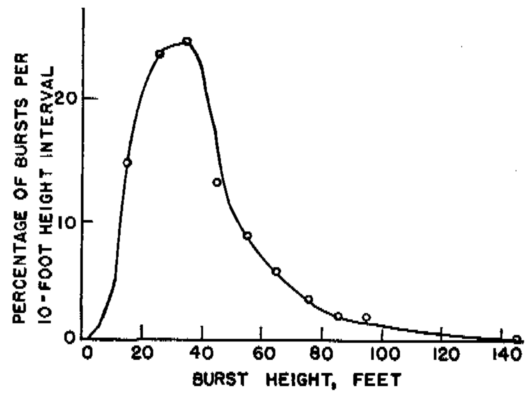


FIGURE 14. Distribution of burst heights of Emerson T-50-E4 fuzes over water (lot group 20).

form and satisfactory performance. Excluded from the table are the first 42 metal parts lots of T-50-E1 that gave a high incidence of duds, and the whole of the T-92 production which

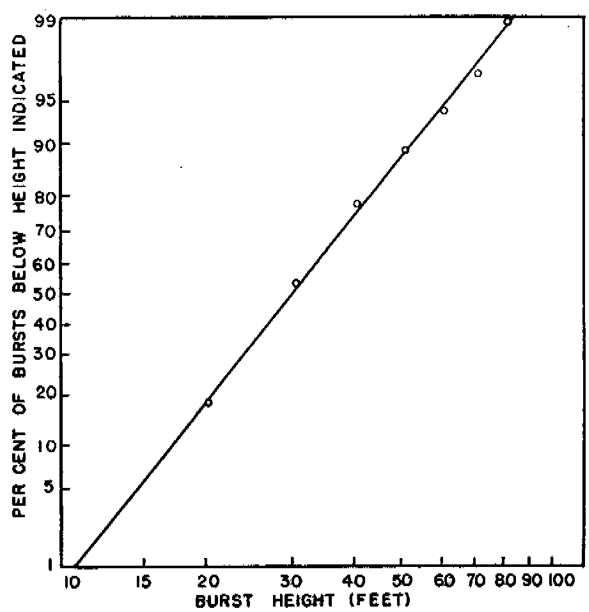


FIGURE 15. Cumulative distribution of burst heights of Philco T-50-E1 fuzes over water (lot group 1).

was rather uniformly unsatisfactory on account of early functioning. Almost no T-92 metal parts were loaded into ammunition lots.

[redacted]

In comparing the performance of Brown and of White carrier fuzes it is apparent that the proper functioning performance of the Brown class is distinctly better than that of the White class, mainly on account of a lower incidence of early functions. This difference would be much more marked if the T-92 were included. On the other hand the overall incidence of duds, 4 per cent, is slightly higher for the Brown carrier fuzes, and would be still higher if the first 42 lots of T-50-E1 were included in the comparison.

TABLE 27. Summary of metal parts acceptance test performance. (Burst heights are for a water target of reflection coefficient 0.81 and a plane speed at release of 200 mph.)

Fuze	Make	No. tested	Per cent scores *P*	*L*	*E*	*D*	Mean burst height (ft)
		Brown carrier fuzes					
T-50-E1 and T-89	Philco and Simplex	1,278	83	0	13	4	35
T-91	Philco	963	87	0	11	2	37
	GE	917	84	0	10	6	44
	both	1,880	86	0	10	4	40
T-91-E1	Emerson	459	92	0	7	1	50
		White carrier fuzes					
T-50-E4 and T-90	Emerson	2,153	77	1	19	3	39
T-92-E1	Emerson	102	79	0	18	3	40

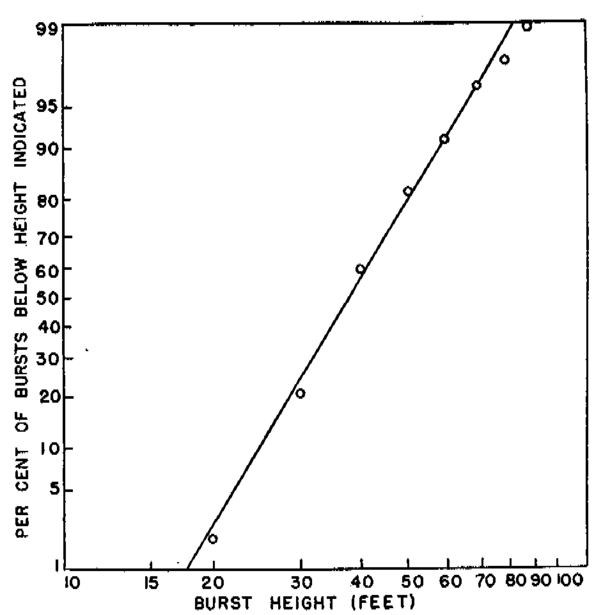


FIGURE 16. Cumulative distribution of burst heights of Philco T-91 fuzes over land (lot group 8).

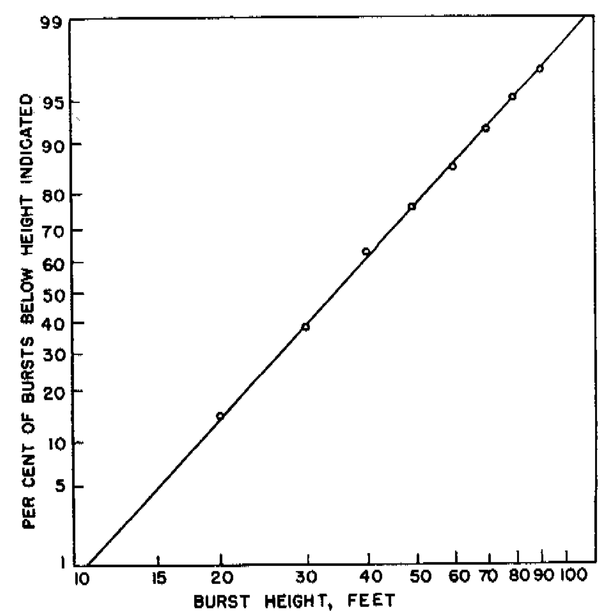


FIGURE 17. Cumulative distribution of burst heights of Emerson T-50-E4 fuzes over water (lot group 20).

SCORES UNDER OTHER CONDITIONS

Uniformity of Performance on Various Vehicles. Although the effect of vehicle size upon performance may be quite marked for fuzes of the ring type (if detuning occurs), observed performance of the T-91 shows very good consistency for several different bomb sizes, as shown in Table 28. There is an apparent improvement in performance on the M-64 bomb but the size of the sample is too small to give the trend real statistical significance.

[redacted]

TABLE 28. T-91 fuzes, performance versus vehicle (from 10,000 ft at 200 mph).*

Vehicle	*Pw*	Per cent *L*	*E*	*D*	Total No. of units
M-30	80	0	17	3	36
M-57	71	0	17	12	24
M-88, -81	81	0	12	7	798
M-64	89	0	7	4	98

* Reference 66, acceptance tests.

Effect of Release Conditions. (1) *Altitude.* In Table 29 are listed scores as a function of altitude of release, without regard to plane speed. A previous examination of the data had shown the latter to have no appreciable effect upon performance. It will be noted that results are fairly uniform (with one exception) with a tendency toward slightly poorer scores for high-altitude releases. The exceptionally high early-function scores for the T-92 units from 10,000 and 20,000 ft should be considered in the light of the discussion in preceding section under "Performance of T-92 and T-92-E1" (pertaining to the data in Table 25).

2. *Train spacing.* The dependence of performance in train release upon the spacing of bombs is influenced by size of the bomb and the use of the delayed arming device. In Table 30 are listed separately results without delays and those with delays. As may be seen, there is no indication of serious effect of train release upon dud score, and the effect upon early functioning decreases as the train spacing increases.

The effect of spacing along with that of the arming delay may best be seen in Figure 18, where the per cent of early functions which occurred sympathetically[f] is plotted against interval between bombs at release.

Because the data are meager, the random variations in results mask to some extent the real effects of the delays and of bomb size as shown in results of the bar-type fuze. There the evidence is strong that arming delays cut down appreciably the sympathetic functioning and that as the spacing increases, the sympathetic functions decrease rapidly.

In Table 30, "int'l" stands for "intentional early." In many train drops, one or more units were set to function on arming, at times later than normal arming time. This insured the occurrence of one or more early functions in order to test the possible response of the other armed fuzes in the train to it. In the table, "sym" means sympathetic function; (Sym $\times$ 100)/E is the percentage of earlies functioning sympathetically as plotted in the accompanying figure.

Oddments. (1) *Washers: Hand versus wrench tightening.*[18] During early testing of bomb fuzes, the general practice became established of mounting units to bombs using a $\frac{1}{32}$-in. lock washer and tightening with a wrench. When it became apparent that the elimination of the wrench would be desirable, a new-type spring washer was introduced and the units were tightened by hand only. This method of mounting proved to be satisfactory for use with both the ring-type and the bar-type fuzes.

A representative score of 83 per cent proper for T-91 fuzes released under standard conditions was obtained using this method.

2. *Navy base plates.*[18] In Naval aircraft launching operations, a fuze protective device was used, consisting of two parts: (1) a metal sleeve, which was released when the bomb was dropped, and (2) a cruciform plate 7 in. in diameter, which served to hold the sleeve in position. This plate remained between the bomb nose and lock washer throughout the entire flight. Tests were made to see what effect the plate had on fuze performance. The results follow:

Unit	Vehicle	Alt.	Speed	No. of *Pw*	*L*	*E*	*D*	Total	%*Pw*
T-50-E4*	M-64	10K	200	6	0	12	0	18	33
T-50-E4	M-64	10K	200	9	0	3	0	12	75
T-91	M-64	10K	200	18	0	0	0	18	100

* There is no known explanation for the difference in performance in the two tests of T-50-E4 units.

3. *Army guide plates.*[18] The performance of T-91 units, assembled on bombs with Air Corps arming-wire guide plates, was tested. No sig-

[f] Early functions which were judged to have been caused by malfunctioning of neighboring units were called "sympathetic" functions. For the purposes of scoring, where photographic data were not available, functions within 0.5 sec or less of the original function were scored as sympathetic. Photographic evidence showed that for the most part, these functions occurred nearly simultaneously.

[redacted]

nificant effect was found. The results are as follows:

Unit	Mfr.	Vehicle	Alt.	Speed	*Pw*	*L*	*E*	*D*	Total	% *Pw*
T-91	Philco	M-88	10K	200	11	0	1	0	12	92
T-91	Philco	M-64	10K	200	12	0	0	0	12	100

4. *Fin thickness.*[74] Sometime during the spring of 1945, excessive early-function scores were obtained in tests of White-frequency units mounted on M-64 bombs. It was found that the metal of the fins on these bombs was thinner than the usual 0.081-in. material. Tests conducted with M-64 bombs having fins of various thickness gave the results in Table 31.

The above results with the 0.081-in. fin are in agreement with acceptance results of the same unit, i.e., 57 per cent proper for 1,000 units. Acceptance tests were made on the M-64 having nominal fin thickness of 0.081 in.

5. *Fin insulators.*[75] In an attempt to reduce the effect of fin upon the incidence of early functions, tests were made with pressboard insulating spacers inserted between the outer rim of the fin and the bomb. Somewhat contradictory results were obtained. In Table 32 are listed results for three types of units dropped under comparable conditions on M-64 bombs, both with and without the insulators. The difference in scores for the T-92 units (disregarding duds) could occur fortuitously one or two times in a hundred. However, the scores for the T-92-E1 and T-50-E4 units show no statistically significant differences.

6. *Delayed arming device.*[76] The delayed arming mechanisms were designed as safety devices and as a means of improving performance of fuzes dropped from high altitudes. The devices have been tested primarily to obtain air-

TABLE 29. Effect of release conditions (single release).

Altitude (ft)	Speed (mph)	Per cent *Pw*	*L*	*E*	*D*	Total No. of units	Bibliographical reference
		Unit T-91				*Vehicle M-57*	
9K-10K*	160-200	71	0	17	12	24	67
3K	255	83	0	0	17	12	
		Unit T-91				*Vehicle M-81 & M-88*	
20K	234-240	89	0	11	0	37	15, 68 acceptance tests
12K	200	73	0	27	0	30	
10K	200	81	0	12	7	798	
6K	200	93	0	7	0	30	
3K	200	90	0	3	7	30	
		Unit T-91				*Vehicle M-64*	
9K-10K	150-200	89	0	7	4	98	69
3K	255	82	0	18	0	11	
		Unit T-50-E4				*Vehicle M-81 & M-88*	
20K-21K	218-240	81	0	15	4	48	70
12K	200	86	0	14	0	22	
10K	200	72	0	24	4	67	
6K	200	95	0	5	0	22	
3K	200	100	0	0	0	22	
		Unit T-50-E4				*Vehicle M-64*	
20K-22.5K	210-240	64	3	33	0	36	
15K	200	92	0	8	0	12	71 acceptance tests
10K	200	76	1	18	5	1,131	
7.5K	200	78	0	17	6	18	
5K	200	94	0	6	0	18	
		Unit T-92				*Vehicle M-64*	
20K	240	55	0	35	10	20	15, 72 acceptance tests
10K	200	58	1	34	8	1,246	
5K	200	85	0	15	0	20	
2.5K	200	85	0	15	0	20	

* K represents 1,000-ft units of altitude.

[redacted]

travel data; a few were tested for performance. The scores of the latter tests follow.

Unit	Vehicle	Alt.	Speed	*Pw*	*L*	*E*	*D*	*N*	% *Pw*	% *E*
T-50-E4	M-64	20K	240	14	0	4	0	18	78	22
T-50-E1	M-81	20K	235	19	0	3	0	22	86	14
T-91	M-81	20K	234	5	0	0	0	5	100	0

TABLE 30. Performance in train,[73] HE-loaded bombs, ring-type fuzes (from 10,000 ft at 200 mph.)

Unit	Vehicle	No. of trains	No. of units	Proper	Low	Early Int'l	Early Other	Dud	No. of Sym	Sym × 100 / E
				*Without DAD**						
				Interval: 15 ft						
T-50-E10	M-81	3	29†	19	0	5	3	0	3	38
T-50-E1	M-64	2	12‡	8	0	0	3	0	1	33
				Interval: 50 ft						
T-50-E10	M-81	5	48‡	33	0	6	8	0	1	7
T-50-E4	M-64	3	18	6	0	3	9	0	4	33
				Interval: 100 ft						
T-50-E10	M-81	2	24	18	0	4	1	1	0	0
				With DAD						
				Interval: 15 ft						
T-91	M-81	3	35§	13	0	6	11	0	6	35
T-50-E1	M-64	2	12	10	0	0	2	0	0	0
				Interval: 50 ft						
T-91	M-81	3	36†	24	0	6	4	0	2	20
T-91	M-64	2	12	9	0	2	0	1	0	0
T-91	M-65	3	6	1	0	3	2	0	1	20
				Interval: 100 ft						
T-91	M-64	3	18	14	0	3	1	0	0	0
T-91	M-65	3	6	1	0	3	2	0	2	40
				Interval: 150 ft						
T-91	M-65	2	4	0	0	2	2	0	1	25

* DAD = delayed arming device.
† 2 unaccounted for.
‡ 1 unaccounted for.
§ 5 unaccounted for.

Although these results indicate no appreciable effect of the delay upon performance, it should be noted that train drops of T-51 units made at Eglin Field indicated marked reduction of earlies by the use of the delay.

BURST HEIGHTS UNDER OTHER CONDITIONS

Effect of Altitude. Predictions of burst heights for various ring-type fuzes as a function of release altitude for level flight at 200 mph have been made using the method described in reference 25 and laboratory data given in Chapter 5. In Figures 19, 20, 21, and 22, predicted heights are represented by solid lines; the dotted lines represent an appraisal of the cumulative error involved in the calculations (from inexactitudes of both electric characteristics and conditions of release).[36] In addition, mean observed burst heights from actual field testing[15, 78] have been spotted in with brackets indicating the standard error of the mean (±1 standard deviation) and the number of rounds upon which the means are based. Figure 23 is a plot of mean observed heights (photographic)

TABLE 31. Effect of fins on performance.*

Unit	*Pw*	*L*	*E*	*D*	Total	%*Pw*	%*E*
			Fin-metal thickness: 0.073 in.				
T-92	33	0	34	5	72	46	47
T-92-RGD	8	0	10	0	18	44	56
T-50-E4	8	0	9	1	18	44	50
			Fin-metal thickness: 0.081 in.				
T-92	42	0	23	6	71	58	32
			Fin-metal thickness: 0.105 in.				
T-92-RGD	14	0	2	2	18	78	11
T-50-E4	24	0	6	0	30	80	20

* All rounds were dropped from 10,000 ft at 200 mph. The difference between the performances with the 0.073- and 0.105-in. fins is highly significant statistically.

[redacted]

versus predicted heights for these tests plus a number of earlier tests in which various experimental model fuzes were involved.[77] Each mean was obtained from a single test.

TABLE 32. Effect of fin insulators on performance.

Unit	Insulator	*Pw*	*L*	*E*	*D*	Total	% *Pw*	% *E*
T-92	Used	32	0	6	3	41	78	15
T-92	Not used	570	100	34	8	1,000	57	34
T-92-E1	Used	17	0	0	1	18	94	0
T-92-E1	Not used	13	0	3	1	17	76	18
T-50-E4	Used	35	1	11	1	48	73	23
T-50-E4	Not used	738	10	163	48	959	77	17

It may be seen that despite rather large discrepancies in some cases between observed and predicted heights, for practical purposes the agreement is satisfactory.

Effect of Vehicle. The design of the ring-type fuze is such that height of burst is affected by the bomb with which the fuze is used. In Table 33 are given mean observed heights $\bar{h}$ for various fuze-missile combinations dropped under standard conditions (from 10,000 ft at 200 mph) along with an estimated standard error of the mean $S_{\bar{h}}$. For comparison are listed also heights for the given combinations predicted by the method outlined in reference 25 using laboratory data given in Chapter 5. Agreement between the two values of heights is satisfactory if allowance is made for a possible 15 per cent error in prediction, as estimated on the basis of reasonable discrepancies in laboratory data and conditions of release.[36]

TABLE 33. Effect of vehicles on function height, ring-type fuzes (from 10,000 ft at 200 mph).

Unit	Mfr.	Vehicle	Predicted height (ft)	$\bar{h}$ (ft)	$S_{\bar{h}}$ (ft)
T-50-E1	Philco	M-81, M-88	34	32	± 0.5
T-50-E1	GE	M-81, M-88	41	43	± 3.2
T-50-E4	Emerson	M-64	49	43	± 0.7
T-91	Philco	M-30	26	28	± 2.3
T-91	Philco	M-81, M-88	28	29	± 0.9
T-91	Philco	M-64	18	22	± 1.1
T-91	GE	M-57	35	45	± 4.9
T-91	GE	M-81, M-88	34	41	± 0.9
T-92	Emerson	M-64	42	34	± 0.6

References 15 and 79, acceptance tests.

Effect of Train Release. Visual and photographic observations indicate that when fuzes are dropped in train, a certain number of functions within the proper range are due, at least in part, to the functioning of neighboring fuzes. This is evidenced by an occasional stacking up of bursts with successive fuzes functioning at increasing heights. The effect of this sympa-

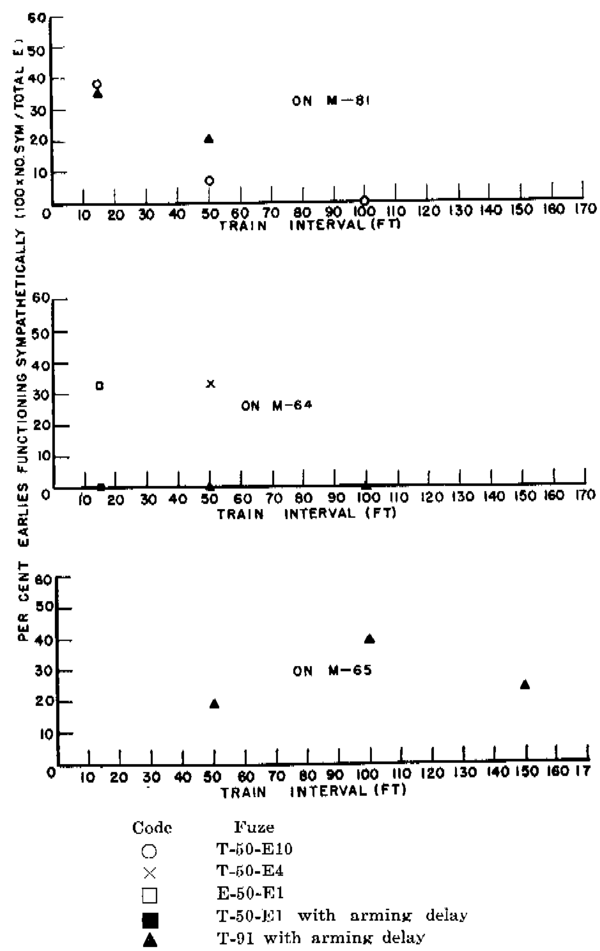


FIGURE 18. Effect of train spacing and of arming delay upon sympathetic functioning of ring-type bomb fuzes on HE loaded M-81, M-64, and M-65 bombs.

thetic functioning among bursts within the proper range would be expected, on the whole, to raise the mean height of function.

From the data tabulated in Table 34, there appears to be no dependence of burst height on this effect. It appears either that sympathetic functioning occurs less often than suspected

from visual observation[g] or that tolerances allowed in the manufacture of fuzes permits variation in burst height sufficient to partially mask the effect. This is further borne out by a Navy test of T-91 fuzes, released in train in a dive of 30 to 45 degrees (at 250 mph), in which with intervals at release of 90 ft the rounds

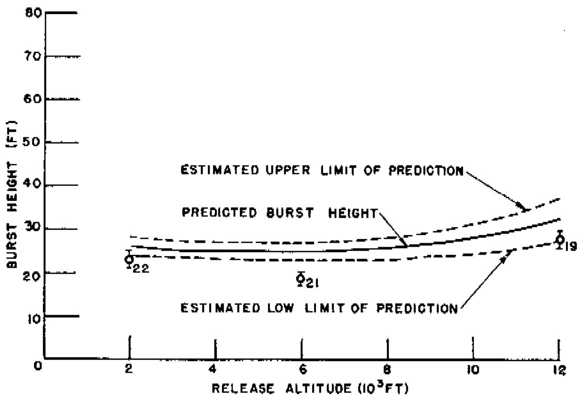


FIGURE 19. Effect of release altitude on burst height of T-89. Vertical bar covers ±1 standard error of mean.

scored as sympathetic propers in one train occurred higher than the regular propers and in another train lower.

TABLE 34. Effect of train interval on function height,[30] HE trains, ring-type fuzes.*

Train interval (ft)	Fuze: T-50-E4 Bomb: M-64 $\bar{h}$ (ft)	$S_{\bar{h}}$ (ft)	T-50-E10 M-81 $\bar{h}$ (ft)	$S_{\bar{h}}$ (ft)	T-91 M-81 $\bar{h}$ (ft)	$S_{\bar{h}}$ (ft)	T-91 M-64 $\bar{h}$ (ft)	$S_{\bar{h}}$ (ft)
15			56	±6.4	31	±3.0		
50	30	±3.5	41	±3.1	34	±3.4	28	±3.3
100			36	±4.3			23	±3.0
∞	43	±0.07			29	±0.87	22	±1.1

* The term $\bar{h}$ = mean burst height. The term $S_{\bar{h}}$ = estimated standard deviation. Heights for single release drops are based on data for inert fuzes.

Spread in Burst Height as a Function of Mean Burst Height. In Figure 24 are plotted values of standard deviation of burst height as a function of the mean burst height. Each point (except a few which cover acceptance testing of particular fuzes) represents the results of an individual test of ring-type fuzes (involving on the average about 10 units). The line shown was determined by the method of least squares.

Although inspection shows that some points fall far from the line, a general trend is defi-

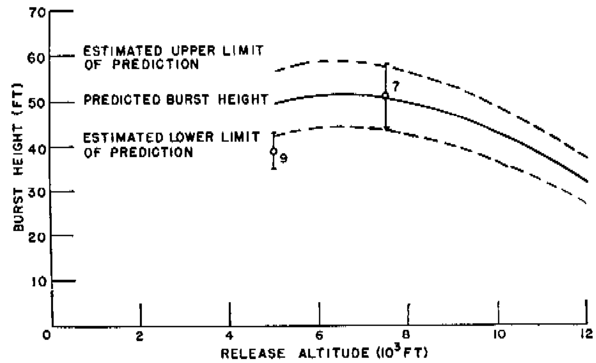


FIGURE 20. Effect of release altitude on burst height of T-90. Vertical bar covers ±1 standard error of mean.

nitely indicated. For the purposes of rough estimates of burst height spread, a measure of this trend has been found useful. As determined from the slope of the straight line, the standard deviation is about 0.4 times the mean height.[34]

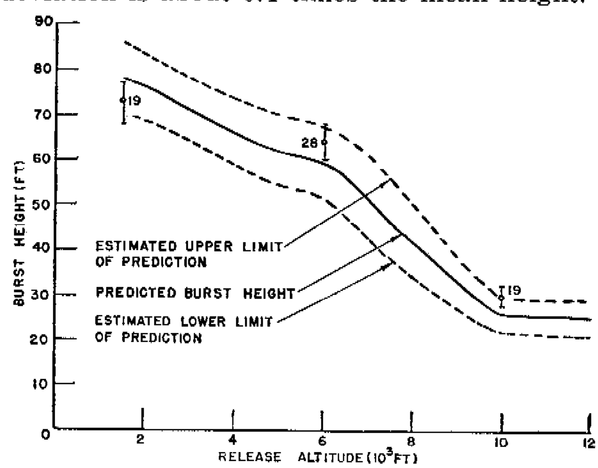


FIGURE 21. Effect of release altitude on burst height of T-91. Vertical bar covers ±1 standard error of mean.

9.4.4 Bar-Type Fuzes

PERFORMANCE UNDER ACCEPTANCE TEST CONDITIONS

General Remarks and Lot Group Data. To the statements made in the first three paragraphs of Section 9.4.3 concerning the acceptance test-

[g] Studies have been made of photographic data to determine actual spacing between bursts which from one location appear to be sympathetic functions. It was found that in many instances these spacings were of such magnitude as to preclude the possibility of interaction.

[redacted]

ing of and presentation of data on ring-type fuzes nothing need be added for bar-type fuzes except the information that the test vehicle was the M-81 (260-lb) fragmentation bomb. The lot group data are given in Table 35 and the group composition in Table 36.

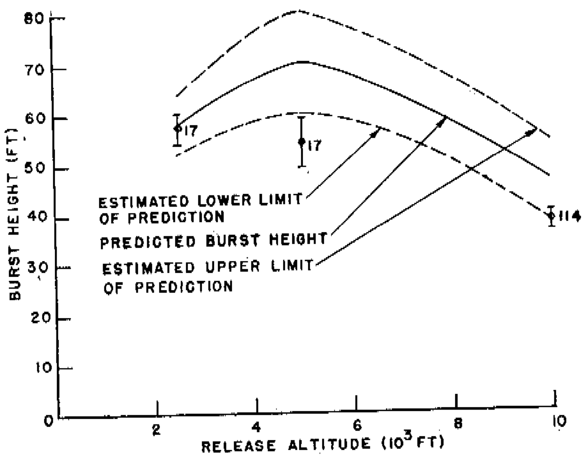


FIGURE 22. Effect of release altitude on burst height of T-92. Vertical bar covers ±1 standard error of mean.

Effect of Test Conditions on Performance. The theory of operation of bar-type fuzes predicts that under the conditions of these tests the effect of changes in plane speed on burst height would be of the same order as the tabulated standard errors of the means. Nothing in the data is to the contrary and this factor is disregarded in estimating overall burst-height performance.

There is no reason to expect the scores to be affected by either plane speed or target factor within the range of the test conditions. It could be shown from an analysis of lot-to-lot per-

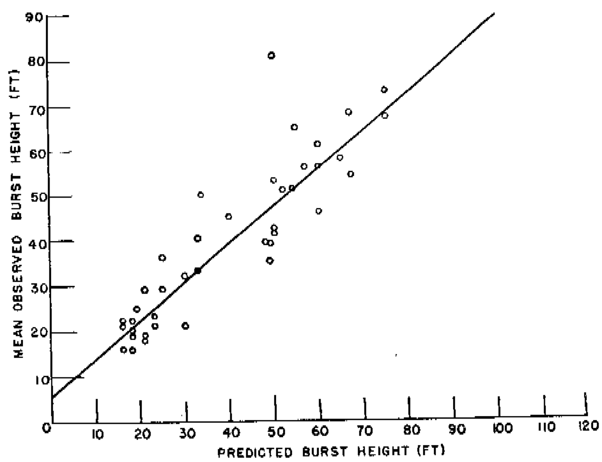


FIGURE 23. Observed versus predicted burst heights, ring-type bomb fuzes. Each point represents one test. Line is the least-squares straight line of best fit.

formance within groups 1 and 7 that there was a general downward trend in early functioning during the early production periods involved. The relatively high early-function scores of these groups thus happen to be associated with higher target factors than the next lot group

TABLE 35. Metal parts acceptance test results.

Lot group No.	Target factor	Number units tested	Per cent score P	L	E	D	Mean burst height (ft)	Standard error mean (ft)
			T-51-E1 and T-51-E2 (Zenith)					
1		590	86	1	13	0	113	1.0
2	65	1,605	91	0	9	0	88	0.5
3*	60	170	92	0	8	0	77	1.4
4*	65	677	91	1	8	0	85	0.9
			M-166 (Zenith)					
5*	60	112	93	0	7	0	74	2.2
6*	65	41	98	0	2	0	84	3.2
			M-166 (Emerson)					
7*	65	300	81	2	17	0	81	1.6
8*	55	149	87	1	12	0	70	1.6
			T-712 (Zenith)					
9*	65	34	100	0	0	0	50	1.9

* Indicates 240-mph nominal true airspeed at release.

[redacted]

in each case. Target factors, plane speeds, and the trends just mentioned are all disregarded in calculating overall performance.

In contrast to the case with the ring-type fuzes, the mean burst heights of the bar-type lot groups are closely associated with the values of target factor, but the relation does not ap-

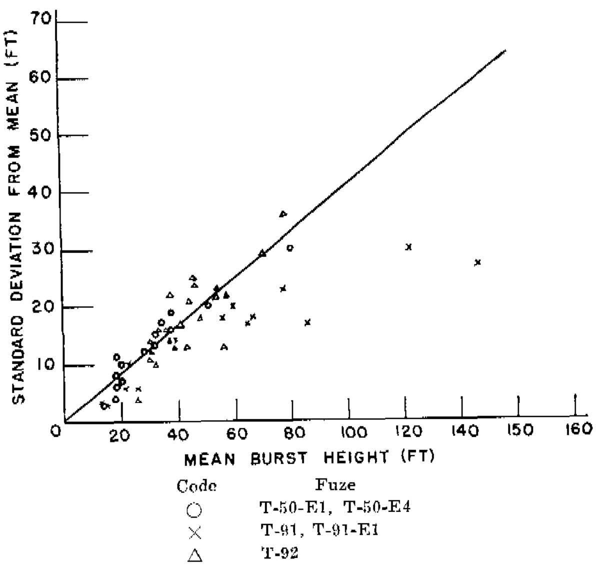


FIGURE 24. Standard deviation versus mean burst height, ring-type bomb fuzes. Each point represents one test.

pear to be one of strict proportionality. The burst height does not appear to change quite as rapidly as the target factor. A small and some-

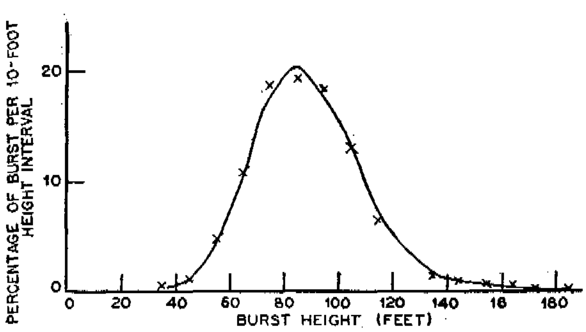


FIGURE 25. Distribution of burst heights of Zenith T-51-E1 fuzes over land (lot group 2).

what arbitrary allowance for this situation is made in adjusting the group burst heights to a common target factor of 81.

Burst Height Distribution Characteristics. The comments made in Section 9.4.3 on "Burst Height Distribution Characteristics" apply equally well to bar-type fuzes. Evidence on the relation between spread and mean burst height of bar-type fuzes is given in the following paragraph. The ratio of spread to mean is in general smaller for bar-type than for ring-type

TABLE 36. Group identification for Table 35. (Duplication in lot number indicates part of the lot was tested under conditions of the particular group number.)

Group number	Metal parts lots
1	CHU 1 through 50, 70
2	CHU 51 through 119, 121 through 158
3	CHU 194 through 198, 205, 206, 227, 228, 230
4	CHU 158 through 191, 199 through 204
5	CHU 5002, 5003, 5005 through 5009
6	CHU 5001, 5004
7	CEX 5001 through 5010, 5014 through 5018
8	CEX 5011 through 5013, 5019 through 5023
9	CHU 192, 193

fuzes, and the distribution curve (see Figure 25) is more symmetrical. A cumulative distribution curve is given in Figure 26.

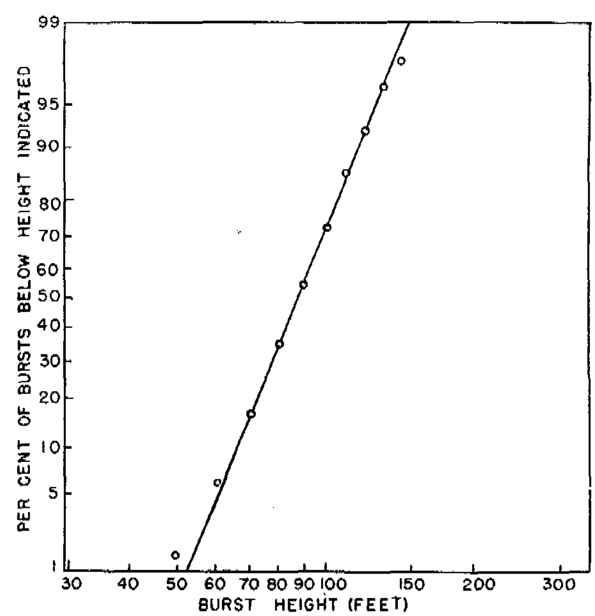


FIGURE 26. Cumulative distribution of burst heights of Zenith T-51-E1 fuzes over land (lot group 2).

Summary of Performance. Apart from the variations mentioned in the preceding paragraph "Effect of Test Conditions on Perform-

ance," the performance of the lot groups of each manufacturer is very uniform. The overall results are given in Table 37. The proper functioning performance of the Zenith product is higher than that of Emerson, mainly on account of the difference in early functioning. It is reasonable to assume that if the Emerson production had continued for a longer period, lower early function scores would have been obtained.

No metal parts lots of bar-type fuzes were rejected.

TABLE 37. Summary of metal parts acceptance test performance. (Burst heights are for a water target of reflection coefficient 0.81.)

Fuze	Make	Number tested	Per cent scores *P*	*L*	*E*	*D*	Mean burst height (ft)
T-51-E1, T-51-E1, M-166	Zenith	3,195	90	1	9	<1	110
M-166	Emerson	449	83	2	15	<1	110

SCORES UNDER OTHER CONDITIONS

Uniformity of Performance on Various Vehicles. The design of the bar-type fuze is such that performance should be relatively independent of the size of vehicle used. The field test results on inert-loaded vehicles, listed in Table 38, show no statistically significant differences in scores. There is a suggestion of somewhat impaired performance for the T-82 on M-57. However, in the absence of any known physical basis for poorer performance on this bomb, it appears that the lower score should be attributed merely to sampling fluctuations. In any event, the effect is not serious. Numerous tests were made also of T-51 on other miscellaneous missiles (fire bombs, chemical bombs, etc.) and uniformly good performance was obtained. Table 39, giving scores from the Eglin Field service test of T-51 units on HE-loaded vehicles,[19] indicates further the consistency of performance from vehicle to vehicle as well as that between inert- and HE-loaded rounds.

Effect of Release Conditions. In Tables 40 and 41 are listed results of single drops as a function of release altitude for inert- and for He-loaded vehicles. In two cases only do the proper scores fall below the 80 per cent mark; both of these are for releases from 30,000 ft.

TABLE 38. Performance versus vehicle, inert-loaded.

Vehicle	Per cent *Pw*	*L*	*E*	*D*	Total No.
*T-82 fuze, released from 10,000 ft at 200 mph**					
M-30	97	0	3	0	30
M-57	68	0	25	7	28
M-88 / M-81	83	0	11	6	480
M-64	73	1	19	7	70
M-65	88	0	12	0	16
M-66	100	0	0	0	10
M-56	100	0	0	0	4
*T-51 fuze, released from 10,000 ft at 200 mph**					
M-57	83	0	16	1	522
M-88 / M-81	87	1	13	0	877
M-64	93	0	7	0	30
M-56†	100	0	0	0	14
M-56‡	100	0	0	0	14

* Reference 81, acceptance tests.

† These tests of T-51 on M-56 were made from various release altitudes (6,000 to 10,000 ft) and over various targets at Aberdeen and Eglin Field.

‡ This group represents T-51 fuzes with reduced sensitivity (about one-half normal) prepared specifically for use on M-56. The average burst height was 74 ft over the water target at Aberdeen. The reduced sensitivity fuze later carried the designation T-712.

TABLE 39. Performance versus vehicle, HE-loaded.

Vehicle	Per cent *Pw*	*L*	*E*	*D*	Total No.
T-51 fuze, released from 10,000 ft at 225 mph					
M-30	100	0	0	0	10
M-81	80	0	20	0	10
M-64	90	0	10	0	10
T-51 fuze, released from 10,000 ft at 175 mph					
M-30	80	0	20	0	10
M-81	80	0	20	0	10
M-64	80	0	20	0	10

The remaining scores are consistently high and indicate little dependence of performance upon altitude of release.

Performance in Train Release, with Special Reference to the Effect of the Arming Delay Device. The effect of train release upon the performance of bar-type fuzes is similar to that found with the ring-type fuze. Dud scores are affected but little, while early functioning is increased as train intervals decrease.

Variations in score with bomb size and with

[redacted]

use of arming delays may be seen in Table 42. The graph in Figure 27 shows how the use of delays and increased spacing cut down sympathetic early functioning.

Table 40. Effect of release conditions (single release), bar-type fuzes, inert bombs.

Altitude (ft)	Speed (mph)	Per cent *Pw*	*L*	*E*	*D*	Total No.
	T-82 Fuzes[82]	*Vehicle: M-88 and M-81*				
22.5K*-25K	235-250	80	3	17	0	36
10K	200	83	0	11	6	480
5K	200	80	0	20	0	10
3K	200	86	0	0	14	42
	T-51 Fuze[83]†	*Vehicle: M-88 and M-81*				
24K-25K	225-250	81	2	17	0	94
20K	210-250	92	0	6	2	48
10K	200	87	1	13	0	877
3K	255	95	0	5	0	20
	T-51 Fuze[84]	*Vehicle: M-64*				
10K	200	93	0	7	0	30
3K	255	100	0	0	0	12

* K denotes altitude in thousands of feet.
† Includes acceptance test results.

Table 41. Effect of release conditions (single release), bar-type fuzes, HE-loaded bombs.[49]

Altitude (ft)	Speed (mph)	Per cent *Pw*	*L*	*E*	*D*	Total No.
	*T-51-E1 Fuze**	*Vehicle: M-30*				
30K†	225-260	65	0	35	0	20
10K	175-225	90	0	10	0	20
5K	150-200	85	0	10	5	20
	T-51-E1 Fuze	*Vehicle: M-81*				
30K	230-270	75	0	25	0	20
10K	175-225	80	0	20	0	20
5K	150-200	93	0	5	2	40
	T-51-E1 Fuze	*Vehicle: M-64*				
30K	230-270	80	0	20	0	20
10K	175-225	85	0	15	0	20
5K	150-200	95	0	0	5	20

* Since a previous examination of the data had shown that the effect of the T-2-E1 device upon performance (in single release) was not appreciable, results with the delay were included in the tables above.
† K denotes altitude in thousands of feet.

The effectiveness of the arming delays in improving performance in train releases is outstanding. For example, in the worst possible cases, M-64 in salvo and minimum train, the use of the delays elevated the proper function score from 57 per cent to a level (86 per cent) that is almost identical with the performance of the fuzes in the metal parts acceptance tests (single release). The results indicate, therefore, that the arming delays are highly effective in eliminating sympathetic early functioning. Indeed there is strong evidence that the proper use of arming delays obviates the need for certain limitations on train spacing that were considered to be of considerable importance until these tests were performed.

Oddments.[18] (1) *Washers, Hand versus Wrench Tightening.* As with the ring-type fuze, the first established method of mounting bar-type fuzes to bombs was with a $\frac{1}{32}$-in. lock washer and tightening with a wrench. The

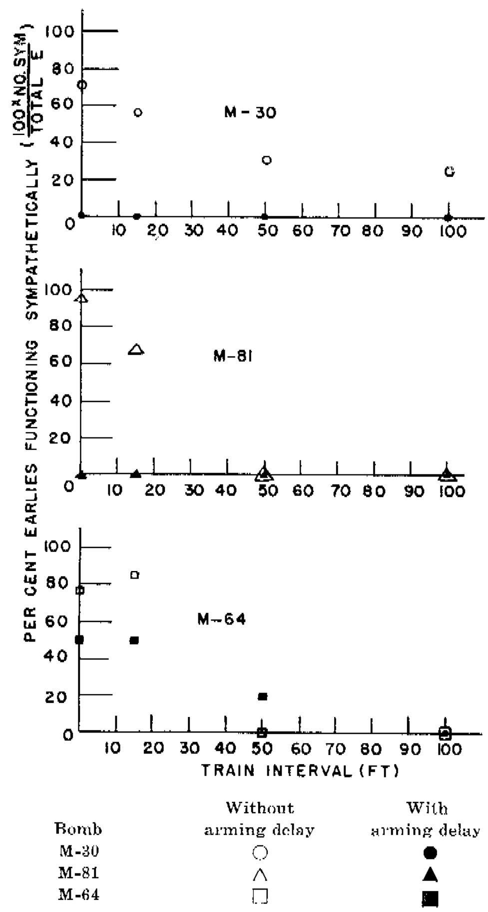


Figure 27. Effect of train spacing and of arming delay upon sympathetic functioning of T-51 fuze on HE loaded M-30, M-81, and M-64 bombs.

effect upon performance of the use of a lock washer and tightening by hand only was tested. The following typical results show no indication of deterioration in performance when these

[redacted]

fuzes are mounted hand-tight instead of wrench-tight.

Alt.	Speed (mph)	Vehicle	*Pw*	*L*	*E*	*D*	*N*	%*Pw*
		T-51 Fuze						
20K	240-250	M-88, -81	22	0	1	1	24	92
10K	200	M-88	30	0	0	0	30	100
		T-82 Fuze						
10K	200	M-88	21	0	2	0	23	91

2. *Army Guide Plates.* The performance of T-51 units assembled on bombs with Air Corps arming-wire guide plates, was tested. Twelve rounds on M-88 from 10,000 ft at 200 mph gave 100 per cent proper function.

No deterioration in performance had been anticipated, and none was observed.

3. *Delayed Arming Device.* Except for train drops of T-51 units in the Eglin Field service test, only a few bar-type fuzes equipped with delayed arming mechanisms were tested for normal approach function. The results are listed below.

Unit	Vehicle	Alt.	Speed	*Pw*	*L*	*E*	*D*	*N*	%*Pw*	%*E*
T-82	M-81	10K	200	9	0	1	0	10	90	10
T-51	M-81	10K	200	8	1	1	0	10	80	10
T-51	M-81	25K	225-250	11	1	0	0	12	92	0

These results are too meager to indicate much improvement in performance. However,

TABLE 42. Performance in train,[49] HE-loaded bombs,* T-51-E1 fuzes (from 10,000 ft at 200 mph).

Vehicle	No. of trains	No. of fuzes	*P*	No. of *L*	*E*	*D*	No. of Sym	Sym × 100 / *E*
			With no arming delay device					
			Salvo					
M-30	2	48	23	1	24	0	17	71
M-81	2	44	3	0	37	4	35	95
M-64	4	48	22	0	26	0	20	77
			Minimum train					
M-30	2	47	38	0	9	0	5	56
M-81	2	44	38	2	3	1	2	67
M-64	4	48	27	0	20	1†	17	85
			50-ft interval					
M-30	2	48	37	0	10	1	3	30
M-81	2	44	40	2	2	0	0	0
M-64	2	24	22	1	1	0	0	0
			100-ft interval					
M-30	2	48	44	0	4	0	1	25
M-81	2	44	37	0	7	0	0	0
M-64	2	24	22	0	2	0	0	0
			With T-2-E1 arming delay device					
			Setting: 7 Div. on M-30, -81. 6 Div. on M-64					
			Salvo					
M-30	2	48	47	0	1	0	0	0
M-81	2	44	42	0	2	0	0	0
M-64	6	58	54	0	4	0	2	50
			Minimum train					
M-30	2	44	39	0	1	4	0	0
M-81	2	44	40	1	3	0	0	0
M-64	5	60	48	0	10	2‡	5	50
			50-ft interval					
M-30	2	48	45	0	2	1	0	0
M-81	2	44	39	0	5	0	0	0
M-64	4	48	42	1	5	0	1	20
			100-ft interval					
M-30	2	48	39	0	8	1	0	0
M-81	2	44	43	0	1	0	0	9
M-64	2	24	20	1	3	0	0	0

* Table combines trains dropped over water and land.
† Low-order detonation.
‡ One function on impact.

[redacted]

the drops in train at Eglin Field showed a marked reduction in early functioning by the use of the delay.

Burst Heights under Other Conditions

Effect of Altitude. Dependence of burst height upon altitude of release is shown in Figure 28. Curves of heights predicted by the method given in reference 33 are shown. Mean burst heights from field testing have been spotted in along with an estimate of their standard error and the number of units involved. It will be seen that if allowance is made for a discrepancy of about 10 per cent in prediction, the agreement between predicted and observed heights is reasonably good.

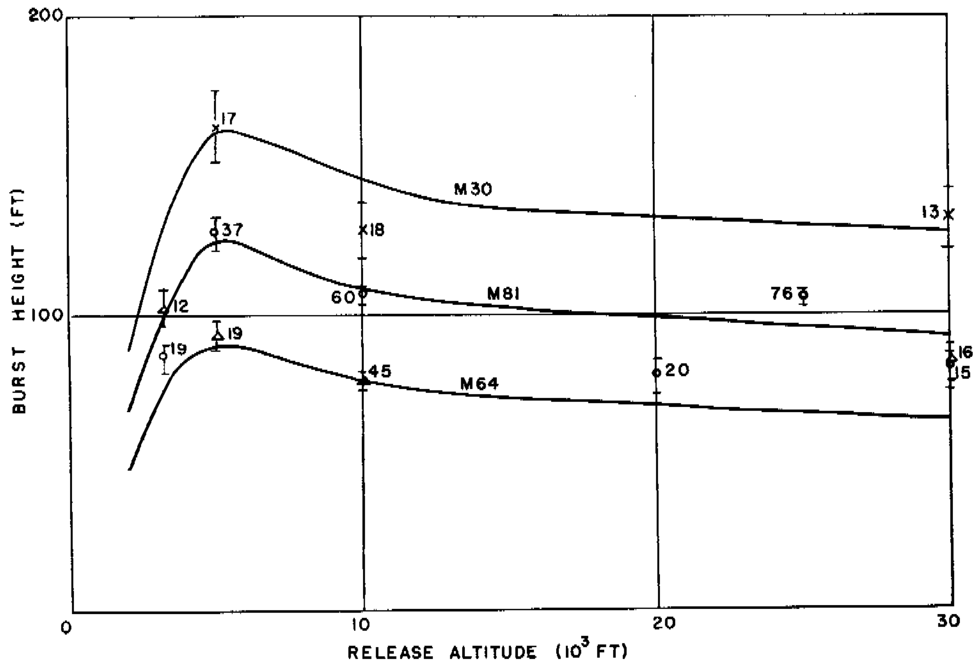


FIGURE 28. Effect of release altitude on burst height of T-51 fuzes on M-30, M-81, and M-64 bombs.

Effect of Vehicle. The effect of vehicle on height of burst of bar-type fuzes is shown in the data tabulated below. Table 43 gives burst heights for single releases over water from 10,000 ft at 200 mph. Table 44 gives the ratio of the burst heights for the fuzes on various bombs to those on the M-81. (Data are based on experimental field tests at Aberdeen, service tests at Eglin Field, and metal parts acceptance tests.) In deriving these ratios adjustments were made when laboratory measurements indicated differences in fuze sensitivity, and when differences in release conditions obtained.

Effect of Train Release. The possibility of sympathetic functioning for the ring-type fuzes in the region of proper burst heights has been discussed in Section 9.4.3. If sympathetic functioning did occur in the proper function zone, one would expect to find the burst height increasing with smaller train spacing. However, the mean burst heights of bombs fuzed with the T-51, as in the case of the ring-type fuzes, do not appear to be affected by train spacing. The mean burst heights for several different bombs and for difference train releases are presented in Table 45.

Spread in Burst Height as a Function of Mean Burst Height. A plot of spread in burst height (see Figure 29) as a function of mean burst height for the bar-type fuze shows much the same trend as that for the ring-type fuze (see Section 9.4.3). In Figure 29 the standard deviation from the mean is used as the measure of spread, each point representing the results of one test. Although the scatter from the line, which was determined by the method of least squares, is in some cases quite marked, for practical purposes a measure of the trend has

TABLE 43. Effect of vehicle on function height (bar-type fuzes).

Fuze	M-30 $\bar{h}$*	M-30 $S_{\bar{h}}$†	M-57 $\bar{h}$	M-57 $S_{\bar{h}}$	M-81 M-88 $\bar{h}$	M-81 M-88 $S_{\bar{h}}$	M-64 $\bar{h}$	M-64 $S_{\bar{h}}$	M-65 $\bar{h}$	M-65 $S_{\bar{h}}$	M-66 $\bar{h}$	M-66 $S_{\bar{h}}$	M-56 $\bar{h}$	M-56 $S_{\bar{h}}$
T-51	142‡	±14‡	121	±1.4	111	±0.9	75	±3.3	77‡	±8‡	44‡	±3‡	157‡	±12‡
T-82	107	±4.6	111	±5.9	120	±1.4	99	±4.5	57	±3.5	57	±4.2	67	±7.7

* $\bar{h}$ = mean burst height in feet.
† $S_{\bar{h}}$ = estimated standard error of the mean. Reference 85, acceptance tests.
‡ These heights estimated from Table 44; no field data available for standard release conditions.

TABLE 44. Ratio of burst heights of various bombs to burst height of M-81 with T-51 and T-82 fuzes.[86]

Bomb	T-51	T-82
M-30	1.28 ± 0.10	0.94 ± 0.05
M-57	1.00 ± 0.05	0.94 ± 0.06
M-88	1.00 ± 0.05	1.00 ± 0.03
M-17	0.60 ± 0.07	
M-64	0.73 ± 0.03	0.86 ± 0.05
M-65, -79	0.69 ± 0.10	0.50 ± 0.03
M-66	0.40 ± 0.06	0.53 ± 0.04
M-56	1.37 ± 0.08	0.49 ± 0.05

TABLE 45. Effect of train interval on burst height,[49] HE-loaded bombs fuzed T-51-E1.

Bomb	Type of release	Salvo $\bar{h}$* (ft)	Salvo $S_{\bar{h}}$† (ft)	Minimum train $\bar{h}$ (ft)	Minimum train $S_{\bar{h}}$ (ft)	50-ft train $\bar{h}$ (ft)	50-ft train $S_{\bar{h}}$ (ft)	100-ft train $\bar{h}$ (ft)	100-ft train $S_{\bar{h}}$ (ft)	100-ft train double susp. $\bar{h}$ (ft)	100-ft train double susp. $S_{\bar{h}}$ (ft)
M-30		128	±7	121	±5	127	±4	142	±5	152	±8
M-81		130	±3	108	±3	126	±4	145	±6		
M-64		60	±5	79	±4	80	±3	92	±3		

* The term h = mean burst height (released over water, from 10,000 ft).
†The term $S_{\bar{h}}$ = estimated standard error of the mean.

been found useful. As determined from the slope of the line, the standard deviation is about 0.23 times the mean height.[34]

9.4.5 Effectiveness of Air Burst

ENHANCED FRAGMENTATION EFFECT

Against Moderately Shielded Personnel. Testing was done at Eglin Field to determine the relative effectiveness of air-burst and contact-burst bombs against moderately shielded personnel (both T-50 and T-51 fuzes were used). Bombs were dropped over an effect field 700x700 ft. The field contained 2,209 replica trenches, constructed as follows. The sides consisted of two rectangular frames 6 ft long and 2 ft wide constructed of 1x6-in. pine. One frame was superimposed on the other to form a box 1 ft deep. The bottoms consisted of ¾-in. plywood panels 6 ft long and 2 ft wide. Trenches were excavated 6 in. beneath the surface, the boxes inserted and leveled, and a sand parapet built around the upper 6-in. frame. The trenches were arranged in columns and rows, 47 each, spaced 15 ft between centers. Odd-numbered columns had the long dimension of the trench in an east-west direction, while those in even-numbered columns had the long dimension in the north-south direction.

In scoring the results, a casualty was defined as one or more "large" perforations through the wooden lining of a trench. In the classification of hits as "large" or "small," a probe approximately $\frac{3}{16}$x$\frac{1}{16}$ in. in cross-sectional area was used. Relatively few perforations were as small as this probe. Figures 30 and 31 show results for single releases from 6,000 ft at 165 mph (chosen to give maximum accuracy of aim and at the same time give the same striking angle as a 10,000-ft, 200-mph release) of 19 M-81 bombs VT-fuzed, as follows: 14 M-64 bombs VT-fuzed; 6 M-81 bombs contact-fuzed (instantaneous); 5 M-64 bombs contact-fuzed (instantaneous) for 3 degrees of shielding. Ten M-1A1 clusters of M-41 bombs, contact-fuzed (instantaneous), were included in

the test. Hits for the various degrees of shielding were included in the count, as follows.

Shielding	Hits Counted
0 in.	On sides and bottom
6 in.	On lower 6 in. of sides and bottom
12 in.	On bottom only

No significantly differing results were obtained in additional releases from 12,000 and 20,000 ft.

In Section 9.2.3, attention was called to the significance of "zero shielding" in the assessment of results obtained on this effect field. From the foregoing description of the field, it is clear that, except for a bomb that strikes inside a trench, a fragment cannot register a hit unless it is traveling in a downward direction from a level above that of a parapet that surrounds a trench. Many of the fragments from a contact-fuzed bomb fail to satisfy this condition. The results of the test are therefore not applicable to a case of troops lying exposed on a mathematically flat plane. The zero-shielding condition approximates more closely a case where troops are lying on a terrain with frequent irregularities of an average height or depth of about 6 in.

Complete analysis and interpretation of the results is somewhat lengthy; reference may be made to the Army Air Forces Board report,[45] where the following conclusion is drawn.

"Under the conditions of this test and for equivalent airplane loads of properly functioning bombs, air-burst M-81 or M-64 bombs are about ten times as effective in producing fragment casualties as are the same bombs or the 20-lb M-41 fragmentation when contact-burst."

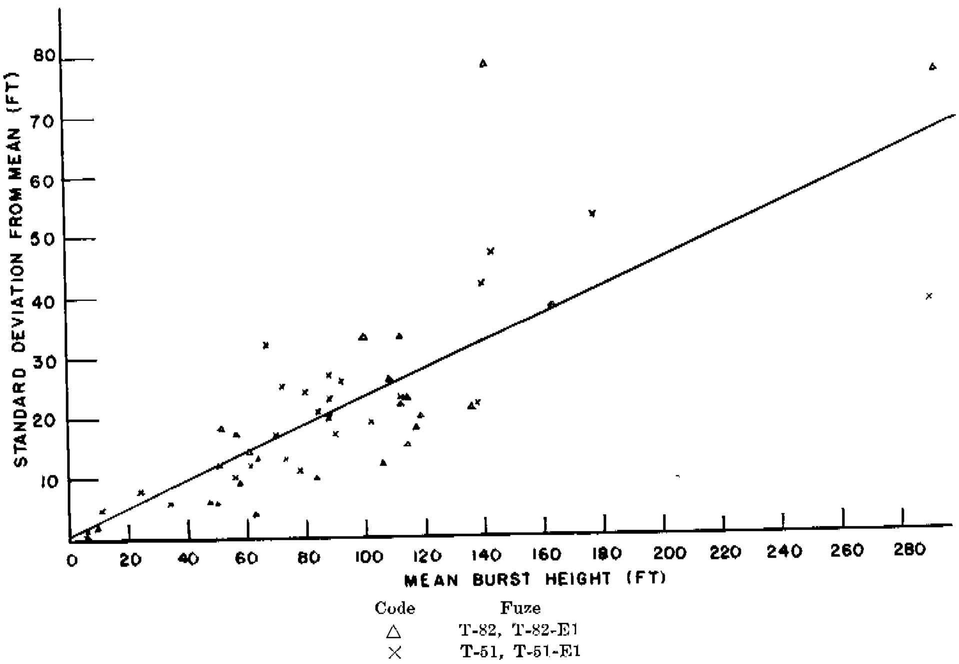


FIGURE 29. Standard deviation versus mean burst height, bar-type bomb fuzes. Each point represents one test.

Against Unshielded and Shielded Personnel and Against Unshielded Matériel. The British carried out an evaluation of air-burst bombs against a composite close support target.[87] American fuzes (T-50 type) and bombs (M-64) were used. Division 4 cooperated in the tests, operating through the London branch of OSRD.

The target consisted of unshielded trenches and simulated prone and entrenched personnel. About 200 trenches 2x6 ft and 1 ft deep were randomly located in an area about 500x1,000 ft. Centered in the bottom of each trench was a 16x46x½-in. target board, simulating the vulnerable area of either three men standing or crouching in a deep trench or one man lying in

a shallow trench. Two boards (10x60x½ in.) nailed together as an inverted trough were placed on the ground near each trench, simulating prone soldiers on reasonably level ground. Thirty-six trenches were scattered at random in the center of the target area. One or more perforations through a board target counted as a casualty. In the case where the boards in trenches represented three men in a deep trench, the number of perforations were counted, and on a probability basis, scored as one, two, or three casualties. Boards destroyed by blast within 50 ft of the burst were scored as complete casualties. Trucks were carefully examined after each bomb burst and only those damaged to the extent that rear-echelon repair was necessary were counted as casualties.

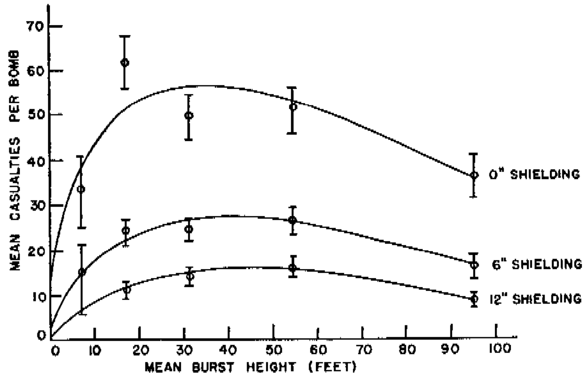


FIGURE 30. Casualties as function of burst height of M-81 fragmentation bomb for several degrees of shielding. Vertical bar indicates ±1 standard error of mean.

Results were expressed in terms of lethal areas. Comparison tests with contact-burst bombs were not made at the same time but previous tests had established vulnerable areas for them under reasonably similar conditions. A summary of the results and comparison data are shown in Table 46.

Against Unshielded Matériel and Deeply Entrenched Personnel. An extensive test to determine the effectiveness of air-burst and contact-burst fragmentation and incendiary bombs against typical enemy defense fortifications was conducted at Eglin Field.[47] Because of the complexities involved in the analysis of the results, details are herein omitted.

From the analysis, it appeared that for totally unshielded trucks and light matériel, a plane load of air-burst bombs was about 80 per cent as effective as one of contact-burst bombs. However, the advantage may be more apparent than real in view of the following considerations:

1. When the results of the test were assessed, it was not known that double suspension of VT-fuzed M-30 and M-81 bombs was practicable. Twenty-four M-30's and 22 M-81's were used as full VT-fuzed loads in B-17 bombers; it now appears that 34 bombs could have been carried without sacrificing good performance.

2. The assessed effectiveness might be greater if account were taken of the likelihood that aircraft would be dispersed in revetments.

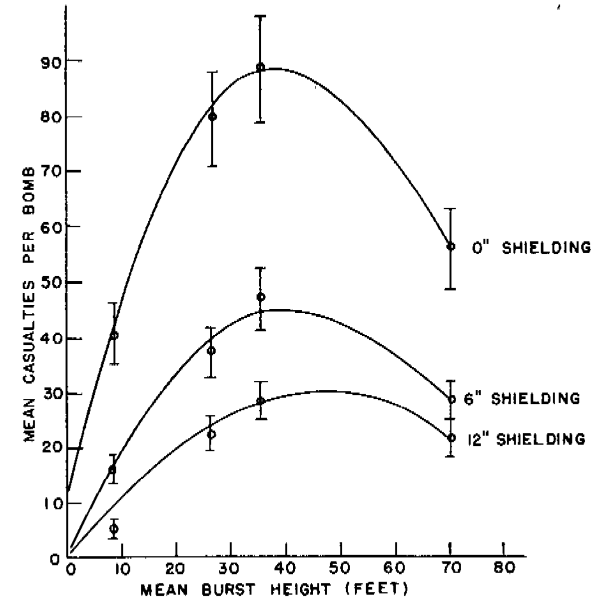


FIGURE 31. Casualties as function of burst height of M-64 GP bomb for several degrees of shielding. Vertical bar indicates ±1 standard error of mean.

As for deeply entrenched personnel (depth of shielding was 5 ft), so slight was the damage done by either air or contact burst that no assessment of relative effectiveness could be made.

Miscellaneous Eglin Field Testing of Effectiveness

During the later stages of World War II, much interest developed in fire bombing with napalm-gasoline gel. Spectacular results were

obtained by dropping fuel tanks of this material from fighter planes flying at such a low altitude that the gel sloshed over a large area immediately after the tanks were ruptured by impact. Under conditions where low-level attack was too dangerous, high-altitude releases of contact-fuzed vehicles gave poor results because a large fraction of the gel remained in the crater. A number of tests were performed with VT-fuzed vehicles to overcome this difficulty. In all cases, the performance of the VT fuzes was satisfactory, and the main problem was to find a container that was available in large quantity in the theaters of operation that could readily be modified into a bomb having suitable bursting and ignition characteristics, suitable ballistic characteristics, and that could be carried economically by fighters or bombers. One improvisation was a modified chemical warfare M-10 (35-gal) spray tank, which gave rather satisfactory results when fuzed T-50-E4, or fuzed T-51-E1 in combination with a "slow" burster.[46] Considerable success was achieved in an extensive program for the development of a vehicle specifically designed for fire bombing, but this program was incomplete when terminated at the close of hostilities.

Enhanced Blast Effect

A number of experiments were performed both in America and in England to determine the possible increased lethality of large blast bombs when air burst. Early in World War II the British prepared a number of special fuzes to provide air bursts on their 4,000-lb *high-capacity* [HC] bomb. Burst heights were set for around 200 ft, which was believed to be the optimum height of function. These bombs were dropped over enemy territory and the damage assessed by photographic coverage. The results showed a decrease in area of demolition and a small increase in area of minor blast damage[92] and, accordingly, interest in the air burst of large blast bombs diminished. Following these tests, work on the T-40 and T-43 fuze projects (see Chapter 1 and Section 3.5) was appreciably curtailed.

However, Division 2, NDRC, and British explosive experts were convinced that demolition from blast could be increased by air burst and set about to determine the optimum height. Extensive small-scale[89] and model-village tests[90] showed conclusively that blast damage could be increased by air burst at the proper height. Optimum heights for a 4,000-lb bomb were estimated at between 40 and 70 ft.[91] Increases in area of demolition were estimated at from 50 to 100 per cent. The conclusions were further corroborated by analysis of the areas of damage produced by a few V-1 bombs which were accidentally air burst in the London area.[92]

No full-scale tests were carried out prior to

TABLE 46. Advantage ratios in favor of 500-lb bombs fuzed T-50.

Target	Height of burst (ft)	Men in deep trenches	Men in shallow trenches	Men prone without cover	Mechanical transport
Effectiveness relative to surface bursts	10	4.0	3.7	1.3	1.0
	36	3.7	5.3	1.2	0.4
Effectiveness relative to a method yielding 50% air bursts using 0.6-sec train spacing*	10	1.8	1.2	1.4	1.6
	36	1.7	1.7	1.3	0.7
Lethal or vulnerable areas (sq ft)	10	5,200	5,600	25,000	38,000
	36	4,800	8,000	24,000	16,000

* This method consisted of dropping a stick of four bombs fuzed with No. 44 pistol (a pressure-activated fuze). Usually two bombs of the train would function on impact and the other two would be air burst, actuated by the blast of the others. Tests with this arrangement had been performed previously.

The British results were in substantial agreement with the Eglin Field results described when due allowances are made for the differences in scoring.[88] The lower ratios of effectiveness reported by the British for air burst were due primarily to the allowances made for blast. This allowance increased appreciably the lethal area of the surface-burst bombs.

Because of the minor differences in effectiveness against personnel for 10- and 36-ft burst heights and the appreciably greater effectiveness of the former against mechanical transport, the British prefer the lower burst heights. In their official requests for American fuzes for their operational use, they specified burst heights of the order of 10 ft.

the end of World War II to verify the above conclusions. However, as is shown in Table 38 above, the T-51 fuze could be modified to operate reliably on the M-56 (4,000-lb) bomb. The British also established that the T-51 fuze could be modified to operate reliably on their 4,000-lb HC bomb.[93]

ENHANCED SPREAD OF GAS

A number of tests were carried out to determine the effectiveness of air-burst bombs in enhancing the spread of mustard-type gas. These tests were made by the British in England and in Anglo-American tests in Panama in simulated jungle warfare. The T-51 and T-82 fuzes were used on British 500-lb light-case [LC] Mark II bombs. In this bomb, which contains two bursting elements, the proximity fuze was located in the nose and an impulse fuze was located in the tail. The actuation of the proximity fuze triggered the tail fuze so that both bursters were effective in dispersing the gas. The results of the tests in England have not been published but have been communicated verbally to Division 4.[94] The results showed that for a 50-ft average air-burst height, the area contaminated to the extent of 1 mg per sq m was approximately 4½ times the area contaminated by the surface burst. For burst heights in the range 100 to 200 ft, the area contaminated (again 1 mg per sq m) was approximately seven times the corresponding area for surface-burst bombs. Publication of the British results was withheld pending an investigation of the inflammability of mustard gas when air burst. Subsequent tests at Panama[95] showed that mustard did not ignite when air burst.

In the tests at Panama[96,97] in which the conditions of jungle warfare were simulated, it was desired to have the air burst just below the level of the treetops in order to contaminate the area under the canopy. It was found that full-sensitivity T-51 fuzes gave air bursts in the treetops or just above, but half-sensitivity T-51 fuzes gave burst heights just below the treetop level and produced an optimum effect. Results from the Panama test were:

1. Thirty bombs impacted on the target area produced an average contamination density of about 2 bombs (containing 350 lb of agent) per artillery square, or about 54 tons of agent per square mile.

2. Vapor dosages greater than 200 mg-min per cu m were attained over about three-quarters of the target area within the first four hours after bombing. Dosages exceeding 1,000 mg-min per cu m were obtained over about one-third of the area in this period.

3. The half-sensitivity T-51 fuze was considered a suitable and desirable fuze for the British bomb, aircraft LC 500-lb Mark II, charged with blister gas for use on jungle terrain.

9.5 FUZES FOR MORTAR SHELLS

9.5.1 General

Since no VT fuzes for mortar shells reached the mass production stage, it is not possible to estimate the quality of performance that could have been attained with production fuzes. Experience with all other VT fuzes showed that performance of mass production models was superior to that of experimental and pilot production models. There is no reason to suspect that experience with mortar-shell fuzes would have been otherwise. It is, therefore, believed that an average measure of the observed performance of the more recent developmental models may be fairly presented as a lower limit for the quality of performance that could be expected of production fuzes based on the development prior to V-J Day.

The presentation of a lower limit for quality of performance is not very satisfactory in evaluating the potential usefulness of a development program, and the data are therefore presented very briefly. Specific test references are omitted. Coverage is defined by a statement of the characteristics of the tests performed during a certain period that are included in the analysis. The source material can be identified by reference to summaries of field test results.[19,20,30,39]

9.5.2 Reliability and Burst Heights

GLOBE-UNION T-132

Performance under Standard Conditions. A

fairly large number of pilot production Globe-Union T-132's were fired in what were called "lot quality tests." These were fired under somewhat similar conditions at Blossom Point and at Clinton Proving Ground. In the summary in Table 47, the analysis is limited to those rounds fired on M-43C shells.[h]

As one would expect, the fuzes differed from lot to lot as test results indicated that changes were necessary. Variations among the units considered in this summary include the following:

1. Amplifier plates: thin or thick horizontal plates.
2. Turbine speed: high (most units) to low (half of high speed).
3. Nose shape: flat (most units) and rounded.
4. Thrust washers: vary in number from one to nine.
5. Regulation circuit: series or parallel; light or heavy loading.
6. Arming: settings were changed occasionally but not enough to affect performance markedly. The above variations did not cause a statistically significant difference among the function scores, and should not affect the function height. The absence of significant difference may be partly due to the small number tested with some variations, but there is no serious objection to pooling the data for the purpose of this summary.

In Table 47, the early functions include those called middle functions at Blossom Point. This grouping was necessary to consolidate the Blossom Point data with the results from Clinton Proving Ground where no distinction between early and middle functions was made. A small fraction, about 4.3 per cent of the proper functions given above, was classed in earlier reports as impact functions. Because the average burst height was in the neighborhood of 10 ft, and because the principle of operation of the fuze makes it improbable for the fuze to function normally at more than three levels between 15 and 0 ft, some functions at water level were to be expected. Detonations initiated at the surface may yield bursts below the surface, on account of delay in the detonator and spotting charge. It is doubtful that any of these functions were actually caused by impact, through either mechanical or electric action.

The poorer scores for firing with charge 4 (Table 47) were being corrected by V-J Day by the use of slower turbine speeds, better thrust washers, and vertical-plate amplifiers (see Chapter 4). These changes would reduce early function and dud scores by reducing breakage of the plates at high acceleration, erratic behavior of the mechanical system at high acceleration and speed, and explosion of rotors by centrifugal force.

TABLE 47. Summary of performance of Globe-Union T-132 for the months of June and July 1945 at Blossom Point and Clinton.

Charge (M-56)	Quadrant elevation (degrees)	N	Per cent P	E	D	H (ft)	N_h*
1	65	270	75	7	18	7	184
1	75, 80	221	85	9	6	8	153
2	65	196	72	13	15	7	67
3	60, 65	249	71	12	17	5	24
4	45	300	60	22	18	15	68
4	65	360	57	19	24	5	150
4	75, 80	94	56	37	6	9	51
Overall scores		1,690	68	16	17	8	697

* Number of rounds upon which height is based.

Performance after Packaging Tests. The only special test which is pertinent to the present discussion is that of performance after packaging tests at Picatinny. Twelve Globe-Union T-132 fuzes from lot GUS-17 were tested in the laboratory before and after being subjected to packaging tests at Picatinny. (The

[h] The M-43C is a combination of the M-43 body and the M-56 tail.

[redacted]

laboratory tests showed changes in electric characteristics which, in view of changes in control units from the same lot not subjected to the packaging tests, were considered caused by aging only.) The field test of these units gave the following results:

Charge (M-56)	Quadrant elevation (degrees)	Number	Per cent *P*	*E*	*D*	Burst height (ft)	$N_{\bar{h}}$
4	45	12	58	8	33	9	7

This score is not significantly different from that in the summary above.

National Bureau of Standards T-171 Fuze

The National Bureau of Standards [NBS] T-171 fuze was used as an experimental unit, and many variations in electric and mechanical systems and in power supply were used. The summary in Table 48 includes only those units with RC arming. The other variations found among these units would be expected to affect function heights obtained with M-56 Ext.[i] shell so that no reliable figure may be given for overall performance in that respect. The average function heights for various tests on this shell varied from 36 to 61 ft. The function scores and heights with the M-43C shell were not affected enough to prohibit pooling the results. Firing conditions were limited almost exclusively to those listed in Table 48.

There are no pertinent tests made with NBS T-171 which are not included in Table 48.

Table 48. Performance of NBS T-171 from June 1 to September 20, 1945.

Vehicle	Charge M-56	Quadrant elevation (degrees)	*N*	Per cent *P*	*E*	*D*	*H* (ft)	$N_{\bar{h}}$
M-43C	2	45	30	77	13	10	14	0
M-43C	4	45	139	65	13	22	20	72
M-56 Ext.	1	45	72	61	17	22	..	..
Overall score			241	65	15	20		

Wurlitzer T-171 and Zenith T-172 Fuzes

Not enough rounds were fired with either of these fuzes to obtain any idea of their probable future performance.

[i] The M-56 shell with a 2-in. rearward displacement of the tail assembly, designed to stabilize flight of the VT-fuzed shell.

9.5.3 Safety and Arming

Globe-Union T-132

General. No data are available on times or distances to complete arming of T-132 units. Summary data on mechanical arming are presented below. The most reliable data are probably the arming times, obtained either from fuzes modified to function on mechanical arming [FOMA] or from fuzes so modified that the carrier signal was extinguished momentarily on carrier indication of mechanical arming [CIMA] (see Chapter 8).

It should be noted that the arming times are approximately inversely proportional to the velocity during burning, so that the mechanical arming distance is nearly independent of the propellent charge. It follows from this that the round-to-round variations in velocity that occur with a fixed charge are reflected in round-to-round variations of arming time. For this reason, it is to be expected that the proportional variation in arming time would exceed the proportional variation in arming distance. A detailed analysis of arming performance is not included here, since a major change in the arming mechanism was under development (see Chapter 4), and would undoubtedly have been used if the fuze had gone into production.

Arming Data. (1) *Arming times.* Arming time of a FOMA unit was obtained by averaging values obtained by several field observers with stopwatches or by averaging the stopwatch times to the end of the phonograph recording of carrier modulation obtained by playing the record several times. Arming time of a CIMA unit was obtained by measurement of a photographic record of carrier modulation or by averaging stopwatch times obtained by playing the phonograph recording of carrier modulation several times. These techniques are described fully in the preceding chapter. Results on arming times are shown in Table 49.

2. *Arming distances.* An attempt was made to measure the slant distance from firing point to function of 47 FOMA units. The work was complicated by photographic troubles and the results, shown in Table 50, may be in error by ± 50 ft.

NBS T-171 Fuze

In order to obtain a unit which would have the electric and mechanical systems isolated as much as possible, most NBS T-171 units were made without an out-of-line element in the powder train. This did away with the gear train running through the entire length of the unit. Arming was accomplished by an RC delay in the firing circuit which prevented firing until a certain time after the generator started to provide plate voltage. This was strictly an experimental design, not intended for Service use. The only available datum on arming of this unit is the time to the earliest function observed in any test.

Table 49. Times to mechanical arming of GU T-132.

Charge	Arming indication	No. of units	Arming time (sec) Max	Min	Mean	SD
	Arming setting: 2,600 turbine turns					
1	FOMA	16	4.2	3.3	3.7	0.37
	CIMA	25	4.3	3.5	3.8	0.36
2	FOMA	6	2.7	2.4	2.6	0.10
	CIMA	6	2.7	1.9	2.1	0.30
3	FOMA	6	2.3	2.0	2.1	0.10
	CIMA	6	2.7	1.9	2.1	0.30
4	FOMA	13	2.2	1.7	1.9	0.23
	CIMA	42	2.2	1.6	1.9	0.20
	Arming setting: 2,400 turbine turns					
1	FOMA	24	4.2	3.4	3.8	
4	FOMA	23	3.8	1.6	2.0	

Table 50. Slant distance to arming of GU T-132.

Charge	No. of units	Slant distance to arming (ft) Max	Min	Mean
	Arming setting: 2,400 turbine turns			
1	24	1,290	1,070	1,170
4	23	1,200	990	1,110

No. of units	R (megohm)	C (μf)	Nominal time to arming (sec)	Minimum time to function (sec)
231	5.0	0.6	2.3	3.9

9.5.4 Ranges

Since the weight of a VT mortar fuze is relatively large compared with the weight of the shell, slight changes in fuze shape and size may result in noticeable effects on mortar shell ballistics. In Table 51, the effect of fuze shape on range is indicated. It should be noted that the effect for the M-56 shell with 2-in. tail extension is not as marked as in the case of the M-43C; this is due to the fact that the drag of the M-56 extension shell is quite large, and the weight of the shell is greater.

The weights of the fuzes, with the exception of the PD fuze, were approximately the same. The T-132A is a streamlined T-132. The T-132B is slightly more streamlined than the T-132A (see Chapter 4). Range data given for the T-171 are based on field tests of fuzes manufactured at NBS. These fuzes had flat noses similar to the T-132. The T-171 fuzes manufactured by Wurlitzer had rounded caps similar to the T-132A, and their ranges were greater than those of NBS T-171. However, no data are available for these fuzes at an elevation of 45 degrees. The T-172 has a loop antenna and cannot be compared in shape to the other fuzes.

The effect of various mortar shell types, fuzed with T-132, on ranges is shown in Table 52. Since the M-43C is lighter and smaller than the M-56, its range is longer. The M-56 with the 2-in. tail extension had the shortest range. (The long tail structure, with its increased space about the powder, caused slower burning. In addition, the increase in projectile length decreased the distance through which the pressure from powder-burning could act. The tail extension, however, increased the stability of the shell.)

It should be remembered that the increments of charge used with the M-43 shell are smaller and of a different type from those used with the other shells. Charge 6 for M-43 is roughly the same as charge 4 for M-56.

No adjustments were made to allow for the effect of wind direction and velocity upon range. Data in Tables 51 and 52 are from field tests conducted at Blossom Point Proving Ground only.

In Tables 51 and 52, the weights listed are those for fuzed projectiles. These weights are only approximate. In the field tests from which the range data were obtained, the proper functioning of the fuze was of primary interest.

The shells were cavitated for permanganate puffs, and no special effort was made to equalize the weights.

The figures in parentheses, following range values, are the number of rounds upon which the ranges are based.

Since in many instances the fuzes were initiated to combat so late in World War II, only preliminary or trial usages were made. Follow-up orders for fuzes after first trials were not fulfilled in time to be of value.

The information presented in this section was taken from operational reports of the Army and Navy.

TABLE 51. Ranges of mortar shells: effect of fuze.[14, 30, 39]

Elevation	T-132 (7 lb, 10 oz)	T-132A (7 lb, 10 oz)	T-132B (7 lb, 10 oz)	T-171 (7 lb, 10 oz)	T-172 (7 lb, 12 oz)	PD M-52B1 (6 lb, 13 oz)
Shell: M-43C Charge: 4						
45°	6485′ (356)	7295′ (6)	7300′ (6)	6445′ (106)	........*	9495′† (12)
Shell: M-56 + 2-in. ext. Charge: 1						
Elevation	T-132 (11 lb, 10 oz)	T-132A (11 lb, 10 oz)	T-132B (11 lb, 10 oz)	T-171 (11 lb, 10 oz)		
45°	2075′ (5)	2170′ (6)	2040′ (6)	2025′ (47)		

* Tests conducted at the Clinton Proving Ground indicate that ranges for T-172 on M-43C shells, fired with charge 4 at 45° quadrant elevation, are approximately equal to ranges for T-132 fired under the same conditions.

† Fired at 46° elevation.

TABLE 52. Ranges of mortar shells: effect of shell type (fuzed T-132).[30] Elevation: 45°.

Charge	M-43 (7 lb, 12 oz)	M-43C (7 lb, 10 oz)	M-56 (11 lb, 8 oz)	M-56 ext. (11 lb, 10 oz)
1	2610′ (3)	2980′ (39)	2500′ (3)	2075′ (5)
2	3780′ (3)	4315′ (50)	3910′ (5)	
3	4270′ (2)	5320′ (40)	5095′ (7)	
4	5205′ (2)	6485′ (356)		

9.6 OPERATIONAL USES OF BOMB AND ROCKET VT FUZES

9.6.1 General

The VT fuzes for bombs and rockets[j] were employed in combat against both the Germans and the Japanese by both the Army and Navy with varying degrees of success. The VT bomb fuzes were used in general-purpose, fragmentation, and incendiary bombs, against antiaircraft (flak) positions, air fields, trains, and light fortifications to give maximum blast and fragmentation effect, and to disperse incendiary material over buildings and troop concentration areas. The VT rocket fuzes were employed in ground-to-ground, air-to-ground, and air-to-air roles to destroy aircraft hangars, aircraft on the ground, aircraft in flight, and to disperse fragments over light machine gun and mortar positions.

9.6.2 Use by Army

The U.S. Army used these fuzes operationally in the various theaters of operations as follows.

European Theater of Operations [ETO]

VT Fuzes, T-5. Approximately 50 T-5 fuzes were employed by the First Tactical Air Force, Seventh Army, during March and April 1945, against hangars, air fields, light and heavy gun positions. No reliable assessment data are available because the targets were in enemy-held territory, but informal information indicated that the results obtained were good. The general conclusion was that a larger number of these fuzes would have been used if they had become available about two months earlier.

VT Fuzes, T-6. None of these fuzes was used in combat in ETO. However, rocket units of the First Army were experimenting with the use of these fuzes during the first months of 1945 and

[j] This section was prepared by Walter G. Finch, former captain in the VT detachment of the Army Ordnance Department.

[redacted]

had fired a total of 40 units in a demonstration with 35 per cent random burst.

Although there was a large percentage of random bursts, the general feeling for the fuze was high. Following the demonstration, the Twelfth Army Group decided that approximately one-half of all rocket projectiles used by the ground forces should be fuzed for air burst and they immediately placed an order for all available T-6 fuzes. It was intended that these fuzes be used to assist in forcing a crossing of the Rhine. However, the crossing was made ahead of schedule without much difficulty. After this occurred, the attitude of the First Army toward the use of rockets had cooled to some extent, and the rocket units were disbanded. There were approximately 79,000 T-6 fuzes available in ETO when World War II ended. In the type of warfare experienced in ETO in the last phases of World War II (a fast-moving offensive), ground-to-ground rocket firing is not usually employed. This type of firing is used when the front lines are stable, and definite positions or areas are to be captured and there is a shortage of artillery weapons. This was not the case in either ETO or the Mediterranean Theater of Operations [MTO].

VT Fuzes, T-50-E1. Approximately 1,300 T-50-E1 fuzes were employed by the Ninth Bombardment Group, Ninth Air Force, during March and April 1945.

The initial mission was carried out on March 15, 1945 by units of the Ninth Bomber Command. Thirty-seven B-26 aircraft participated in the attack, carrying a total of 524 260-lb (M-81) fragmentation bombs. The target areas were located at Pirmasens and Neunkirchen, Germany, and consisted of important flak positions guarding avenues of approach into inner Germany. The aircraft, flying in formations of three and six at 15,000 ft, released the bombs at 100-ft train spacing. Visual, verbal, and written reports indicate that the flak was reduced considerably and in some cases stopped completely.

Additional missions were against similar positions with similar results.

It was apparent that the using arms would have used more of these fuzes in ETO if they had been available there. Two days before the war in ETO ended, a cable was dispatched to the Air Ordnance Office in Washington, D. C., requesting immediate air shipment of 5,000 T-50-E1 fuzes to the theater.

Mediterranean Theater of Operations [MTO]

VT Fuzes, T-5. These fuzes were not employed operationally in MTO because of Air Force tactics. When the air forces employed rockets for use against the enemy, they sent their planes into combat in close proximity to the ground. This prohibited the use of the T-5 fuzes because of range dispersion at shallow dive angles.

VT Fuzes, T-6. The initial use of VT fuzes (T-6) occurred during the week of March 12, 1945 when rocket units of the Fifth Army fired the 4.5-in. rockets from ground mounts for the first time in MTO. The target was a small hamlet at the foot of a mountain across a deep valley. It is estimated that 70 per cent of the 100 units fired operated normally. Rockets were not used extensively in MTO because of the fact that they were too erratic, and the using and artillery arms did not have much confidence in them because of the large range dispersion. During March and April approximately 500 units were used in combat; at least 70 per cent functioned satisfactorily. Deep interest was displayed in the VT fuzes for rockets by the using arms, and it was felt that these fuzes had great possibilities.

VT Fuzes, T-50-E1. The Fifteenth Air Force used approximately 1,500 T-50-E1 fuzes in combat up to May 1, 1945. These fuzes were employed in 260-lb fragmentation bombs against enemy flak positions that defended an avenue of approach into Austria and Germany. The initial use was on April 1, 1945 when 18 aircraft of the Fifteenth Air Force dropped 213 260-lb fragmentation bombs (M-81) against four 4-gun German flak batteries located in six different target positions near Grisolera, Italy.

The excellent pin-point bombing secured many near misses on three of the four batteries assigned. The B-24's pilots were briefed to attack in two waves of nine aircraft composed

[redacted]

of three 3-ship elements. Each element was assigned a separate 4-gun battery. All of the batteries attacked in the first wave ceased firing when the bombs exploded, even though one of the four batteries was missed by several hundred yards. Fifteen minutes after the first wave attacked, the second wave dropped their bomb load over the same positions and reported that all flak firing ceased as the bombs exploded. Both waves received light, inaccurate antiaircraft fire on their bomb runs which were made between 24,000 and 26,000 ft. No American planes were damaged nor were any losses sustained. Ground scores indicated that 22 soldiers were killed, 18 were wounded, and one 20-mm gun was destroyed.

Analysis of strike photographs taken on the mission indicated further that (1) there were a number of early bursts, (2) that when the fuzes functioned properly the detonation occurred approximately 17 ft off the ground, (3) that the distribution of fragments from each bomb over the ground was approximately circular, and (4) that the fragments were not uniformly dense throughout the pattern.

Later attacks under similar conditions yielded results comparable to these of the first mission.

VT Fuzes, T-51. The Twelfth Air Force used approximately 100 VT fuzes, T-51 in 260-lb fragmentation bombs, 500- and 1,000-lb GP bombs, and the 165-gal fuel tank incendiary bombs against enemy positions. The results of the combat tests indicated that the fuzes could be used to initiate 500- or 1,000-lb GP bombs or the 260-lb fragmentation bomb could be employed successfully against personnel or equipment targets that are sheltered from ground level artillery projectiles or bomb bursts by walls, revetments, or fox holes. The users concluded that the fuzes could also be employed effectively in carpet bombing in support of a ground forces' offensive.

VT Fuzes, T-51-E1. The Twelfth and Fifteenth Air Forces were ready to start employing the T-51-E1 fuze when it was announced that the war had ended in MTO. There were 10,000 of these fuzes on order from the Zone of Interior and they were scheduled for delivery in May 1945.

Pacific Theater of Operations [POA]

VT Fuzes, T-5 and T-6. None of these fuzes was used operationally in the Pacific War Zone.

VT Fuzes, T-50-E1 and T-50-E4. (1) The total fuzes expended by the Army in POA until August 1, 1945, were 1,426 T-50-E1 and 1,656 T-50-E4 fuzes.

2. A demonstration was held on January 22, 1945, at Saipan for introducing the VT fuzes into the POA. Twelve proximity-fuzed bombs were dropped and all the fuzes functioned properly and gave normal heights of burst.

3. The first VT fuze missions in POA were

a. February 10, 1945. Target attacked: Air installations Iwo Jima. Ten B-24's carried 95 500-lb GP bombs fuzed with T-50-E4 fuzes. Results: Crews reported 65 per cent hit in the target area. Photos showed air bursts to have hit over a widespread area but very thinly dispersed except for one heavy concentration of hits in the easternmost corner of the target area. Several bombardiers reported that a good percentage of the bombs exploded prematurely (1,500 to 2,000 ft below the formation).

b. February 10, 1945. Target attacked: AA defenses, radio and radar northeast of air field No. 3, Iwo Jima. Results: 75 per cent of the 50 500-lb bombs, fuzed with T-50-E4 fuzes, hit in the target area. The fact that AA fire ceased shortly after bombs away indicate the possibility that this strike rendered at least some of the AA guns inoperative.

4. Two additional missions were carried out against Iwo Jima, several against Marcus Island, and some at Ryukyus and Kyushu. All attacks were either against AA installations or airfields. Sketchy reports concerning stopping of AA fire or early functioning of some of the fuzes was essentially all the information received concerning the effectiveness of the proximity-fuzed bombs. Typical action photographs are shown in Figures 32 and 33.

China, Burma, India Theaters of Operations [CBI]

It is estimated that approximately 600 VT fuzes were expended in CBI against flak positions and light fortifications.

VT Fuzes, T-50-E1 and T-50-E4. (1) The

Tenth Air Force expended 75 T-50-E1 fuzes in 260-lb fragmentation bombs against AA positions in the air preparation for landings at Rangoon. All the fuzes operated normally.

2. The Twentieth Air Force employed 74 T-50-E1 and 349 T-50-E4 fuzes in 260-lb fragmentation and 500-lb GP bombs on two night raids against flak positions and light installations. The function of the fuzes was reported as excellent, with AA fire stopped and huge fires started. This air force placed an order for 179,000 T-51 type fuzes.

FIGURE 32. Strike photograph from bomber, illustrating fragmentation patterns obtained on beach fortification area, Iwo Jima, February 17, 1945. Patterns are from several trains of 260-lb fragmentation bombs, fuzed T-50-E1, released from 5,000 ft. (Army Air Forces photograph.)

3. The Three Hundred and First Fighter Wing employed 74 T-50-E4 fuzes on August 15, 1945 against enemy positions. Because of a slight overcast, it was difficult to observe the results.

VT Fuzes, T-51-E1. The Fourteenth Air Force dropped a total of 96 T-51-E1 fuzes against enemy AA positions, buildings of Chinese construction, and entrenched personnel, 48 on 500-lb GP bombs, 32 on 250-lb GP bombs, and 16 on 260-lb fragmentation bombs. In all cases where VT-fuzed bombs were used, they functioned properly and effectively. No malfunctions were observed.

9.6.3 Use by Navy

The U. S. Navy employed the VT fuzes for bombs with success against the Japanese. These fuzes were used in missions against antiaircraft gun positions, light buildings, and personnel in the open. The aircraft carrier USS *Randolph*, for example, employed a considerable number of the fuzes in the last six weeks of World War II. From July 1 through August 15, 1945, the carrier's aircraft dropped a total of 2,240 bombs of all sizes over Japanese targets. Of this number, approximately 800 of the bombs were fuzed with VT fuzes or 35 per cent of the total number of bombs dropped during the period were VT fuzed.

Other examples of the percentage of VT fuzes, T-50-E1 and T-50-E4, used in combat during the latter stages of the war with the Japanese are listed below.

From July 10 to August 15, 1945

Aircraft carrier	VT fuze, 260-lb frag.	T-50 type 500-lb GP	Conventional fuze, all types of bombs	% VT
USS *Bennington*	348	170	1,204	30
USS *Independence*	242	11	431	37
USS *San Jacinto*	212	95	712	30
USS *Shangri-La*	584	185	1,300	37

Reports on Effectiveness. Following are extracts from various Navy reports on the use of VT bomb fuzes.

1. Excerpt from Report USS *Yorktown* for the period from May 24 to June 13, 1945, support of Okinawa operations:

> VT fuzes were used with both 260-lb fragmentation and 500-lb GP bombs, this ship's first experience with these fuzes. Pilot observations as to fuze functioning and bomb effectiveness were necessarily limited because of the high release altitudes required with these fuzes and the type damage done by fragmentation bombs, but the pilots were generally enthusiastic about the possibilities of this type of attack. The latest VT fuzes, which have reasonably low minimum release altitudes, in fragmentation bombs promise to be excellent weapons for use against revetted aircraft and personnel targets.

2. Excerpt from brief of Commander Task Group 38.4, dated May 24 to June 13, 1945:

VT fuzes were employed for the first time during this operation. Functioning of the fuzes appeared satisfactory, but an accurate count could not be obtained. The best available information indicates about ten per cent were duds, exploding on impact and another ten per cent exploded prematurely. Some of the prematures were possibly caused by close proximity to other bombs. The high release altitude required to arm these fuzes is a distinct disadvantage. Fuzes requiring shorter travel to arm should be made available as soon as possible. VT fuzes are a valuable addition to our offensive armament, but it is felt that strafing is still the primary means of destroying revetted aircraft.

3. Extract from a Task Force 38 report, dated June 8, 1945:

This operation is given separate treatment because it was specifically planned to avoid the difficulties of the previous Kyushu sweeps. Tactical concentration and saturation of defenses were achieved by having all available VF and VBF strike a single airfield system in a coordinated plan over the shortest possible time interval. Ample time was allowed for careful target assignment and briefing. An approach track which allowed the enemy minimum warning was selected. Finally, a weapon was selected (260-lb fragmentation bombs, VT-fuzed) which apparently effectively attacked revetted aircraft and anti-aircraft positions. This operation was entirely successful; considerable damage is estimated to have been done the enemy with the loss to ourselves of no pilots and only four airplanes.

FIGURE 33. Strike photograph from bomber, illustrating fragmentation patterns obtained on air field at Tsuiki, northern Kyushu, August 8, 1945. Bombs were 260-lb fragmentation, fuzed T-50-E1, released from 10,000 ft. Some bombs burst over water, giving sharply defined fragmentation patterns (Army Air Forces photograph).

4. Aircraft launched from the USS *Ticonderoga* on June 9 and 10, 1945, were used to drop 260-lb fragmentation bombs fuzed with T-50-E1 fuzes and 500-lb GP bombs fuzed with T-50-E4 fuzes on antiaircraft positions on Minami Shima and Kita Shima. The pilots of the aircraft estimated that 90 per cent of the 106 VT-fuzed bombs dropped functioned normally and that the antiaircraft fire from the

islands, in general, ceased after the attack.

5. Excerpt from brief of action reports and analysis of strike on Wake Island, June 20, 1945, ComCarDiv 11, USS *Hancock*, USS *Lexington*, and USS *Cowpens:*

Fighters were used exclusively on anti-aircraft and several installations appear to have been knocked out. Favorable reports were made on the effectiveness of the air burst (VT) fuze by Air Group SIX. This group employed their VT bombs in what appears to be a most effective manner. The first dive was made for the sole purpose of releasing the air burst fuzed bombs, the second pass, using their rockets and machine guns, led the bombers in to the target. It is interesting to note that none of the Hancock bombers were hit. While the white phosphorus bombs seem to have functioned normally, it is believed that a certain amount of training is required by the pilots carrying this bomb to provide practice in placing the bomb properly with relation to the target, and by bombers who must learn how to wait until the smoke cloud has had time to develop fully before coming within AA range.

The attacks at Wake were characterized by more extensive anti-flak measures than naval A/C have perhaps ever used from the point of view of ordnance and tactics. When the strike group sighted the island at about 30 miles, anti-flak VF broke away, flew in ahead and attacked threatening AA positions with VT fuzed bombs (usually 260-lb frags) and White Phosphorus Bombs. VF then rejoined the group orbiting 10 to 15 miles away and a coordinated attack followed with VF rocketing and strafing AA positions a few seconds ahead of VB, VT, and VBF.

260-lb Frag M-81 with VT Fuzing: Reports of observers indicate that this bomb and fuzing may be very effective. Several AA installations, medium and heavy, were definitely silenced, but whether this can be attributed to personnel or material casualties cannot be determined at this time. Photographs do not reveal definite material damage, although it may be extensive.

1,000-lb GP Bombs with VT Fuzes: An experienced ACI officer observer believes that use of this bomb must have caused extensive damage, although again it is not revealed by photographs. Bursts were just above ground and high enough to clear revetments.

VT Fuzes T-50-E1 and T-50-E4: This fuze is very effective and must be carefully considered in planning bomb loading. One dud was reported although all VT-fuzed bombs also had tail fuzes. No prematures were reported. The relatively high point of release for arming is a disadvantage in pinpoint bombing, but the T-90 series VT fuzes should tend to overcome this defect. The results of this operation indicate that VT-fuzed bombs should be highly effective against heavily revetted positions, anti-aircraft positions, personnel, parked aircraft, and vehicles. If pilots were experienced in train release of VT-fuzed bombs, more practical loadings could be made. In this operation only one VT-fuzed bomb per plane was used.

It is believed that the use of the VT-fuzed bombs by the anti-flak fighter planes of the Air Group was highly successful against anti-aircraft positions attacked on Wilkes Island and Wake Island. Two medium AA near the Marine Camp of Southwest Wake Island were permanently silenced after a VT bomb attack and some of the many guns at and near Peacock Point may have been knocked out. VB and VTB encountered almost no AA fire on their attacks although attacking VF were subject to fire from heavy, medium, and light AA. It is reasonable to believe that the VB, VRB, immunity was due to the anti-flak attacks preceding the bombing runs. Commander of VBF 6 reported that the VT-fuzed bomb burst left wide circular residual smoke on the ground estimated at least 300 ft in radius. Plainly the aerial bursts with their wide-spread fragmentation and blast damage may have inflicted substantial casualties to personnel, aside from their psychological and morale effects.

Some uneasiness was experienced by pilots in using the VT-fuzed bombs at the possibility of the arming wire slipping out and the bomb being armed by its air travel while still hung on the wing rack.

The T-50-E1 and T-50-E4 fuzes require too high minimum-release altitudes for accurate bombing. Issue of the newer T-91 and T-92 fuzes, when available, will materially increase the effectiveness of the VT bombs.

This Air Group dropped a total of 42 bombs with VT aerial burst bomb fuzes. Very little tangible results could be observed from the use of these bombs. In some instances pilots observed slight aerial disturbances over targets where bombs were dropped with slight dust clouds and other debris. Since no personnel were observed, the effect of these bomb bursts against personnel could not be ascertained.

As target coordinator on certain strikes, I observed no tangible evidence of the effect of the bombs bursting in the air except the slight dust disturbances. No diminishing of AA fire can be definitely attributed to these bombs. Some of these VT-fuzed bombs were seen to explode by contact. However, due to pilots inability to observe bomb explosions during dives, there may have been many more bombs exploded by contact.

AirPacComment: The "slight dust disturbances" mentioned arise from impact of fragments on the ground about the burst. The presence of such a dust pattern, and of an orange explosion and black smoke billowing in all directions, is evidence of an aerial burst. Damage visible from the air will seldom be inflicted by VT-fuzed bombs, but the extent of the dust pattern will show the extent of the pattern of lethal and damaging fragments. The concussion of a nearby aerial burst, particularly of a large GP, is also likely to be somewhat unsettling to AA gunners.

6. Excerpt from CO USS *Cowpen's* report, dated June 23, 1945:

[redacted]

The effectiveness of subject bombs (VT fuzed) was difficult to observe from the air. Pilots were at times unable to judge whether the bombs burst on or above the ground, but the consensus of opinion is that the majority of bursts were above ground level.

Two observed cases of reduction of AA fire after attack with subject bombs were noted as follows:

(a) Medium AA fire from the vicinity of . . . apparently ceased after strikes one and two.

(b) Heavy AA positions at . . . were attacked, and at least two very close air bursts were obtained. Heavy AA guns were observed firing from this position immediately prior to attack. Five VF aircraft of VF-50 made a second dive on this position five minutes later, and all pilots stated definitely that the guns were not firing on the second attack.

In the opinion of the Commander, . . . , the 260-lb fragmentation bomb with VT fuze is an excellent weapon for attacks on revetted positions and is far superior to WP bombs and to rockets. It is recommended that two such bombs per VF aircraft would make an excellent load for all attacks on AA positions, personnel, grounded aircraft or vehicles. When the 260-lb fragmentation bomb becomes available, it should be even better for this purpose.

Due to the fact that salvo drops of VT-fuzed bombs are inadvisable, it is further recommended that, if practicable, VF bomb releases be rewired through the rocket selector box so that drops in train may be made more easily.

7. Excerpt from action report USS *Essex*, July 2 to August 15, 1945:

VT Prematures: No accurate statement can be made of the number of VT prematures dropped by bombers, but it is estimated to be below 10 per cent. The majority of prematures appear to have been dropped by fighters who released higher than bombers. It is estimated that the number of prematures from fighters was sometimes over 50 per cent. The only prominent variables involved were that fighters carry these bombs externally and that they be released at speeds 70 to 100 knots higher than the bombers. It is suggested that experiments be conducted to determine whether speed at release has any effect on premature bursts. It was the opinion of most of the pilots that the premature bursts were 500-lb GP bombs rather than 260-lb frags. There can be no certainty about this observation, since judgment could be made only from the appearance of the burst, but it is an indication that the fuze used with the 500-lb GP is more susceptible to premature functioning than the one used with the 260-lb frag.

VT-Fuzed Bombs: Greatly increased damage per ton of bombs dropped on revetted and parked airplanes is believed to result from the use of T-50-E1 VT-fuzed frag bombs. However, somewhat less enthusiasm is felt for the T-50-E4 VT-fuzed 500-lb GP bombs. In the case of the latter, a considerably higher percentage of "prematures" is indicated from the overall evidence that is available. Further, the actual total damage per load of bombs is believed to be greater (assuming 100 per cent correct fuze performance) in the case of the 260-lb frag bombs. Also, the rather strenuous ordeal of the TBM to attain a climbing or cruising speed high enough to satisfy the SB2C's, F6F's, and F4U's at 16,000 to 20,000 ft altitude when loaded with 4 x 500-lb bombs, brings to issue a point in favor of the lighter load of 6 x 260-lb bombs.

8. Excerpts from CNO, memo, dated July 14, 1945:

VT-Fuzed Bombs: On the Kanoya strike 8 June, VT fuzes were used for the first time. These were attached to all bombs released over the target area (52 260-lb Frag and 11 500-lb GP). Pilots observed a few premature bursts, but the general opinion was that functioning of these fuzes was satisfactory and that the area was well covered with bursts exploding close to and above ground.

9. Excerpt from Commander Air Force, Pacific Fleet on Japan Operations July 10 to 18, 1945:

VT-fuzed bombs used extensively against parked A/C in the Tokyo district are believed to be an ideal loading for this type of target. Some high bursts were observed, but the number of these was less than the anticipated 10 per cent. The required high release altitudes in reducing bombing accuracy emphasized the importance of issuance of the new T-91 and T-92 fuzes.

The VT fuzes referred to were of the T-50 type.

10. Excerpt from USS *Lexington* action report, dated August 4, 1945:

This Air Group dropped a total of forty-two (42) bombs with VT aerial burst bomb fuzes. Very little tangible results could be observed from the use of these bombs. In some instances pilots observed slight aerial disturbances over targets where these bombs were dropped with slight dust clouds and other debris. Since no personnel were observed, the effect of these bomb bursts against personnel could not be ascertained.

The target coordination observed no tangible evidence of the effect of the bombs bursting in the air except the slight dust disturbances. No diminishing of AA fire can be definitely attributed to these bombs. A total of three VT-fuzed bombs were seen to explode by contact. However, due to pilots inability to observe bomb explosions during dives, there may have been more bombs exploded by contact.

11. Excerpt from action report, USS *Bennington*, dated August 31, 1945; operations against the Japanese homeland from Western Honshu to Eastern Hokkaido:

VT Fuzes. Although positive damage assessment is extremely difficult, it is believed that VT fuzes have

performed extremely well and that they have solved the long-present air burst fuze problem. If all safety precautions are strictly followed, they are as safe as the conventional fuzes and no trouble whatsoever will be encountered.

9.6.4 Summary of Conclusions Made by Using Arms

An analysis of operational reports by the services yielded the following general conclusions:

1. The general attitude of the using arms to the bomb and rocket VT fuzes at the end of World War II was most favorable. Originally there was much doubt as to their possible value as a lethal weapon. The general attitude was that the fuzes had very limited use, that they were unsafe, and that a high percentage of them malfunctioned. Combat experience in the various theaters changed this view, and with the close of World War II the using arms were very enthusiastic over the fuzes.

2. The operational use of VT bomb and rocket fuzes, particularly in ETO and MTO, was retarded by transmission to the theaters (by the AAF) of unfavorable data taken at Eglin Field on preproduction fuzes. This information caused a feeling that the fuzes were not ready for operational use at that time and necessitated a great deal of experimenting in the combat area to see if they performed satisfactorily and were safe. Exhaustive preoperational tests were conducted in both ETO and MTO before employing the fuzes operationally.

3. These fuzes could be used effectively to explode 260-lb fragmentation bombs or 500- or 1,000-lb GP bombs on personnel or equipment targets that were sheltered from ground level artillery projectiles or bomb bursts by walls, revetments, or fox holes.

4. These fuzes could be used effectively in carpet bombing in close support of a ground force offensive. It was felt that an area could be saturated with bomb fragments at an angle that is most effective against personnel occupying defensive positions.

5. These fuzes could be used effectively for neutralizing concentrated flak positions, such as were found on many of the Pacific islands. Bombers at high altitudes can identify flak positions and drop 260-lb fragmentation bombs with VT fuzes accurately enough to cause a diminution of accuracy and intensity of AA opposition.

6. These fuzes could be used effectively with 500- and 1,000-lb GP bombs mounted under the wings of fighter aircraft.

7. The T-5 and T-6 type fuzes had very limited use because of our superiority in airpower and the high dispersion of the M-8 rocket.

8. The T-50-E1 and T-50-E4 type fuzes gave an operational performance of 70 to 75 per cent in actual combat, based on reports submitted from the various theaters. These figures are lower than test results of 80 to 85 per cent obtained in the United States, and this is probably due either to incomplete counts or to poor installation of the fuzes in the combat areas.

9. Ground reports from special agents indicate that fragmentation bombs with VT fuzes reduce morale and accuracy of flak personnel, kill and injure flak personnel, and cause damage to AA equipment, such as cables, directors, and radar units.

10. In attacking flak positions, it was found by the Ninth and Fifteenth Air Forces that the best tactics were to attack each position in elements of threes instead of a large number of planes in close formation.

11. In addition a number of suggestions were made for improving or modifying the fuzes. These included

   a. That the percentage of random bursts, especially the early bursts, be reduced both for psychological and economic reasons.

   b. That arming delays be supplied with all bomb fuzes being shipped in order to improve fuze performance and give an added margin of safety whenever possible.

   c. That provision be made for shorter arming times, particularly for dive bombing.

   d. That extra lock washers be supplied with shipments of the fuzes, since they are usually flattened during installation or removal of the fuzes.

   e. That a streamlined windshield be developed to cover the arming vane for those fuzes that are employed in bombs that are

[redacted]

mounted under the wing racks in fighter type aircraft.

f. That corrective measures be instituted to eliminate breaking of cotter pins on arming vanes and thus causing duds.

g. That a suitable wrench be shipped with the fuzes for tightening the fin-locking nuts on the various bombs.

h. That improvements be made in the arming wire method of preventing vane rotation, with particular attention to bombs carried under the wings of fighter planes. Although the arrangement appeared satisfactory when properly installed, an error in installation would allow the arming wire to be pulled out by air drag while still mounted on the wing.

9.7 SUMMARY AND CONCLUSIONS

Pertinent summary data of this volume on radio proximity fuzes were presented in the introduction, particularly in Sections 1.4 and 1.5. The reader may therefore refer to Chapter 1 for summary information.

With proximity fuzes established as important and practicable ordnance items, it is desirable that development work continue. In the various preceding chapters, as well as in this chapter, the limitations and deficiencies of the fuzes developed during World War II have been discussed. Future work will naturally attempt to eliminate these deficiencies. It has been pointed out in several places in the volume that numerous compromises in design were necessary for reasons of expediency. In an orderly long-term peacetime development, such compromises should be less difficult to resolve.

A detailed discussion of the limitations of the fuzes previously described and methods for improvement should not, however, be made here, for two important reasons.

1. Advanced thinking and more sophisticated development on radio proximity fuzes will be classified "secret" much longer, according to present classification policy, than will the material presented in this volume. Accordingly, the possible circulation of this volume would be appreciably curtailed by including, just in suggestive form, some of the most promising ideas for fuze improvements. The material in this volume has been presented, as far as possible, in a form to provide a basis for further development. The subject matter of Chapter 2, in particular, is fundamental to any fuze design which involves the interaction of radio waves with a target. Thus, it does not seem desirable to impair the possible usefulness of this volume by including a little new and much more restricted material which is of unproven merit.

2. One of the main reasons for outlining suggestions for possible future work is to urge that such work be undertaken. The Army Ordnance Department, one of the agencies to whom this report is made, has already formulated a vigorous fundamental development program on proximity fuzes. Assumption of responsibility for further development was started by the Army prior to the end of World War II and is continuing. Division 4's central laboratories, the Ordnance Development Division at the National Bureau of Standards, are now working for the Army Ordnance Department on new fuze problems. Thus, with an active far-reaching program on proximity fuzes already under way, it becomes superfluous to suggest here what form that program might take.

The important thing is to insure that the accumulated technical information and experience of World War II period is available in an orderly form for those who will continue the work. It is hoped that the preceding pages of this volume have fulfilled that objective.

9.8 APPENDIX TO CHAPTER 9 ACCEPTANCE TEST CONDITIONS

9.8.1 Acceptance Testing of Bomb Fuzes

A program for acceptance testing of VT bomb fuzes was established early in 1944. Since then minor variations in acceptance requirements have been made. Basically the testing procedure has remained unchanged. Every manufacturer's lot, considered for acceptance, was subjected to two types of field tests: a metal parts assembly test, followed after acceptance by a loading test of ammunition lots, which

usually involved several metal parts lots. An outline of Army Ordnance specifications for these tests follows:[51]

A. Metal Parts Test

1. A ballistic sample of 18 metal parts assemblies (fuzes) prepared for testing will be shipped to the Proving Ground from a loading plant.

2. Metal Parts to be tested will be assembled to bombs, as follows:

a. T-50-E1, T-89—Bomb, Frag, 260 lb, AN-M81.

b. T-50-E4, T-90—Bomb, GP, 500 lb, AN-M64.

c. T-51, T-51-E1—Bomb, Frag, 260 lb, AN-M81 or Bomb, GP, 250 lb, AN-M57.

d. T-91—Bomb, Frag, 260 lb, AN-M81.

e. T-92—Bomb, GP, 500 lb, AN-M64.

The AN-M64 and AN-M57 will be sand loaded. The AN-M81 may be used empty (empty-weight 220 lb). The bombs should be equipped with a suitable spotting charge. Every precaution will be taken that both the fuze and tail fin assembly are tightly screwed to the bomb. (Not possible to unscrew by hand. A wrench is provided to tighten the fuze.)

3. All bombs will be dropped singly in the normal manner from an aircraft flying at a true air speed of 200 ± 5 mph from a true altitude of 10,000—1,000 ft above the target.

4. *Normal Test Plan.*

a. Seventeen metal parts assemblies will be tested for a first sample.

b. *Requirement for Acceptance*—12 or more assemblies shall cause proper functioning.

c. Retest sample will contain 23 metal parts assemblies.

d. *Requirement for Acceptance on Retest*—26 or more assemblies.

5. *Reduced Test Plan.* (This plan was discontinued April 3, 1945 by order of Army Ordnance.)

a. Six metal parts assemblies will be tested for the first sample.

b. *Requirement for Acceptance*—5 or more assemblies must cause proper functioning.

c. Twelve metal parts assemblies will constitute a retest sample.

d. *Requirement for Acceptance on Retest*—a total of 10 or more assemblies out of the entire 18 tested shall cause proper functioning.

6. The following procedure applies to the Reduced Testing Plan of Paragraph 5 above:

a. If 10 successively produced lots offered for acceptance by a manufacturer are accepted under the Normal Test Plan the producer is placed on a preferred list which entitles him to have his product tested on the basis of the reduced testing criterion.

b. Such a manufacturer will remain on this basis until a lot is rejected on the basis of the Reduced Test Plan. The producer will then return to the Normal Testing Plan basis.

c. Requalification as explained in (a) above will be necessary in order for the manufacturers product to be again tested on the Reduced Testing Plan.

7. Height of burst for proper function will depend on the nature of the target area. If the metal parts assemblies are tested over water the height of burst for proper functions are fixed and are listed below. If the assemblies are tested over land the required heights for proper function shall be determined by multiplying the required height range for testing over water by a target factor which is to be determined at least twice during the testing period of a day. This factor depends upon variables of the target area. Necessary equipment to obtain this information and personnel to install and instruct in its use will be arranged through the Office, Chief of Ordnance. The following figures constitute the range of proper functioning when the fuzes are tested over water:

T-50-E4, T-50-E1, T-89, T-90, T-91 and T-92—between 10 and 160 ft.

T-51, T-51-E1—between 60 and 240 ft.

B. Loading Tests

1. Accepted metal parts lots will be received at the loading plant and be assembled into a grand lot for loading. Lot for loading will generally consist of more than one metal parts lot of one manufacturer. From each loaded lot a ballistic sample of 20 fuzes will be shipped to the Proving Ground for test.

2. The sample sent to the Proving Ground will be tested for the following qualities:

a. Minimum Safe Air Travel (abbreviated MinSAT).

b. Functioning quality of the loading components.

3. The Loading tests will consist of 2 phases. Phase 1 is a test of the MinSAT of the lot and conducted with inert bombs; phase 2 is a test of functioning quality of the lot and is conducted with HE bombs. Phase 1 is based upon an altitude of release from which no arming should occur before impact. Phase 2 is based upon an altitude of release from which the majority of the fuzes should arm before impact.

4. Arming of VT bomb fuzes is dependent upon the size and shape of the bomb as well as its ballistic character of flight; therefore, it is desirable to conduct phase 1 of the test on the bomb which will give the fuze the least MinSAT with which that particular model of fuze may be used. At present this bomb is the AN-M30 or the AN-M81 for all models.

5. Below are tabulated the requirements for conducting Loaded Acceptance Tests of VT bomb fuzes.

6. Phase 1 may be released in train at any desired interval and should impact on normal soil. Phase 2, if desired, may be released in train providing AN-M30 and AN-M81 bombs are spaced with at least 50 ft. interval and AN-M57 and AN-M64 are spaced with at least 100 ft. interval. Phase 2 may be tested over water or land. Phase 2 should not be conducted if a lot fails on phase 1.

7. A lot of fuzes should be rejected if it fails to meet the requirements of either phase 1 or 2 of this test.

[redacted]

Upon rejection, a retest will be authorized only by the Office, Chief of Ordnance.

9.8.2 Acceptance Tests of Navy Rocket Fuzes

A procedure similar to that used for bomb fuzes was followed in the acceptance testing of the T-2004 rocket fuze. The major part of the rocket testing program was done in accordance with Army Ordnance specifications of May 1945.[52, 53] A summary of these specifications is given below.

A lot was tested in two phases: first a metal parts test, and then, provided the first had been passed, a loading acceptance test.

Fuze, Bomb, Nose, VT, T-50-E1 & T-89, 3,600 ft MinSAT (Sample Containing 20)

Phase	Quantity	Bomb	True airspeed (mph)*	True altitude (ft)*	Requirements for acceptance
1	10	†AN-M81 inert (empty) with spotting charge	200	1,750 — 200	10 duds
	5	AN-M30 HE	200	3,200 + 200	8 or more high-order functions
2	5	AN-M81 HE	200	3,200 + 200	

Fuze, Bomb, Nose, VT, T-50-E4 & T-90, 3,600 ft MinSAT (Sample Containing 20)

Phase	Quantity	Bomb	True airspeed (mph)*	True altitude (ft)*	Requirements for acceptance
1	10	†AN-M81 inert (empty) with spotting charge	200	1,750 — 200	10 duds
	5	AN-M30 HE	200	3,200 + 200	8 or more high-order functions
2	5	AN-M64 HE	200	4,100 + 200	

Fuze, Bomb, Nose, VT, T-51 or T-51-E1, 3,600 ft MinSAT (Sample Containing 20)

Phase	Quantity	Bomb	True airspeed (mph)*	True altitude (ft)*	Requirements for acceptance
1	10	AN-M81 (empty) with spotting charge	200	1,700 — 200	10 duds
2	10	AN-M57 HE	200	3,400 + 200	8 or more high-order functions

Fuze, Bomb, Nose, VT, T-51 or T-51-E1, 4,500 ft MinSAT (Sample Containing 20)

Phase	Quantity	Bomb	True airspeed (mph)*	True altitude (ft)*	Requirements for acceptance
1	10	AN-M81 (empty) with spotting charge	200	2,400 — 200	10 duds
2	10	AN-M57 HE	200	4,500 + 200	8 or more high-order functions

Fuze, Bomb, Nose, VT, T-91, 2,000 ft MinSAT (Sample Containing 20)

Phase	Quantity	Bomb	True airspeed (mph)*	True altitude (ft)*	Requirements for acceptance
1	10	†AN-M81 inert (empty) with spotting charge	200	600 + 100	10 duds
	5	AN-M30 HE loaded with Arming Delay, Air Travel T2E1 set at 3 Divisions	200	3,900 + 200	4 or more high-order functions
2	5	AN-M81 (empty) with spotting charge	200	1,350 + 200	4 or more functions

Fuze, Bomb, Nose, VT, T-92, 2,600 ft MinSAT (Sample Containing 20)

Phase	Quantity	Bomb	True airspeed (mph)*	True altitude (ft)*	Requirements for acceptance
1	10	†AN-M81 (empty) with spotting charge	200	900 — 200	10 duds
2	5	AN-M30 HE loaded with Arming Delay, Air Travel T2E1, Dial Setting at 3 Divisions	200	3,900 + 200	4 or more high-order functions
	5	AN-M64 empty (sand-loaded to weight) with spotting charge	200	2,400 + 200	4 or more functions

* The true altitude and true airspeed at release should be carefully adjusted as the results of this test depend nearly entirely upon them. Only level flight, true altitude and true airspeeds as listed will give the correct results.

† If AN-M81 empty bombs are not available, AN-M30 sand-loaded bombs may be used.

[redacted]

Metal Parts Test. In general, 17 fuzes from each manufacturer's lot tested were fired over water on 3.25-in. Mk-7 motors with empty 3.5-in. Mk-5 heads. The rockets were launched singly from a ground rail installation with a firing elevation of approximately 30 degrees.

Fuzes from every tenth lot, however, were fired from a plane over a water target at any convenient dive angle not less than 20 degrees. Plane speeds were approximately 250 mph.

Requirements for acceptance: Twelve or more units were required to function properly on approach to water. (Mid-flight functions after 6 sec of flight time were considered proper functions.) Proper function height limits were 10 to 100 ft. No function was to occur before 450 ft of air travel.

In case of failure a retest of 23 additional units was made. Twenty-six of the total of 40 units tested were required to function as indicated above.

Loading Test. Lots which had passed the metal parts test were loaded at Picatinny Arsenal and combined into larger lots. These were subjected to a mechanical arming test and to a functioning test.

Mechanical arming test: Ten fuzes, wired to function on mechanical arming, were fired on 3.25-in. Mk-7 motors with 5.0-in. Mk-1 HE heads. The rockets were launched singly from a ground rail installation at any convenient elevation.

All fuzes were required to function between 290 and 650 ft of air travel. The failure of more than one fuze to cause the rocket to burst with a high-order detonation caused rejection of a lot.

If a lot failed, a retest of 20 additional fuzes could be made at the request of the contractor, provided (1) no burst had occurred before 290 ft, (2) not more than one burst had occurred after 650 ft, and (3) not more than two fuzes had failed to cause the rocket to burst with a high-order detonation.

For acceptance of a retested lot, it was required that on the basis of the total of 30 fuzes tested (1) no burst occur before 290 ft, (2) not more than two bursts occur after 650 ft, and (3) not more than three fuzes fail to cause the rocket to burst with high-order detonation.

Functioning test: Ten fuzes, set for normal functioning, were fired over water on 3.25-in. Mk-7 motors with 3.5-in. empty Mk-5 heads. Rockets were launched singly from a ground rail installation at an elevation of approximately 30 degrees.

A lot was accepted if no fuze functioned before 450 ft of air travel and not more than two fuzes failed to function.

If a lot failed, a retest of 20 additional fuzes could be made at the request of the contractor. The retested lot was accepted provided on the basis of 30 fuzes tested (1) no burst occurred before 450 ft, and (2) not more than four fuzes failed to function.

A number of lots tested under this program were accepted despite the fact that they failed to meet the requirements of the mechanical arming test. It was later found that, with high ambient temperatures, the air travel was insufficient for the 100 propeller turns under acceleration necessary for the first stage of the arming process. In August 1945, revisions were made in the original specifications.[54, 55] All lots which were retested under the new specifications passed. The highlights of the changes made follow.

Metal parts test

1. Testing from aircraft was eliminated.
2. Proper function limits required for acceptance were made 10 to 70 ft, with an average height of about 35 ft.

Mechanical arming test

1. Projectile: 3.25-in. Mk-7 motor with 3.5-in. Mk-5 head.
2. All functions were required to occur between 300 and 850 ft of air travel.
3. Retest requirements were changed in accordance with these new limits.

Loading-functioning test

1. Projectile: 3.25-in. Mk-7 motor with 5.0-in. Mk-1 head (inert loaded to 48 lb).
2. Rockets were to be fired over ground from a plane at any convenient dive angle less than 20 degrees, and at an altitude to give a minimum flight time of 4 sec. Plane speed: 275 mph approximately.
3. Requirements for acceptance: No fuze should function before 1.9 sec flight time; not more than two fuzes should fail to function.
4. Corresponding changes were made in retest conditions.

9.8.3 Acceptance Testing of T-5 Fuzes

From February 1943 to May 1944, acceptance tests were made on 365 lots of T-5 fuzes. For the first six months, the tests were conducted

by NBS at Fort Fisher and Blossom Point. The mock-plane targets and firing towers used at these proving grounds are described in Chapter 8. Later testing was conducted by Army Ordnance at Aberdeen Proving Ground. A rectangular wire mesh screen, stretched between four poles, was used as the target there.

The acceptance requirements at all three proving grounds were essentially the same. Salient features are given below.

Test Procedure. Twenty units, from each lot of 1,000 to be tested, were mounted on Revere or Budd $4\frac{1}{2}$-in. rockets, and fired horizontally from a tower for function on approach to a target approximately 70 ft above ground.

Requirements for Acceptance. At least ten units were required to function properly. In a considerable part of the testing, firing was stopped as soon as ten proper functions were obtained.

Method of Scoring. In order that a unit be counted in scoring, it had to pass within the radius of action of the target. For the mock-plane targets used at Fort Fisher and Blossom Point, the scoring region was defined by a circle of 60-ft radius, cut off by a plane 40 ft above the ground (because of the possibility of ground firing).

Functions were classified as proper, early, late, or dud. A proper function was one occurring not more than 60 ft before the center of the wing of the mock-plane target, and not later than 35 ft after. Functions occurring before and after the proper-function limits were classified as earlies and lates respectively. A dud was a unit which failed to function.

Retest conditions: If a lot failed the normal test, 60 additional units were fired. At least 44 proper functions, based on the total of 80 units tested, were necessary for acceptance.

[redacted]

GLOSSARY[a]

A. Approach. Representing fuze function on approach to ground target.

A Voltage. The voltage applied to the filaments of vacuum tubes.

A Winding. The winding or coil on the generator power supply which furnishes A voltage.

Afterburning. Afterburning is burning in the rocket motor occurring after the main burning or acceleration period. See Sections 9.2 and 9.3.

Amplifier. That part of a radio proximity fuze which amplifies the doppler signal to a magnitude sufficient to fire a thyratron.

Amplifier Gain. Ratio of amplifier output voltage to amplifier input voltage.

Antenna. The radiator or exciting portion of a radio proximity fuze; the bars in a transversely excited fuze, the ring in a longitudinally excited fuze, the conical cap in the T-5 fuze, or the loop in the T-172.

Antenna Gain. Ratio of the power transmitted per unit area in a given direction relative to that from an isotropic antenna having the same total radiated power. See Section 2.8.

Antenna Reactance. The reactance occurring in the parallel resistance-reactance combination which is equivalent to the antenna. See Section 2.7.

Antenna Resistance. The resistance occurring in the parallel resistance-reactance combination which is equivalent to the antenna. See Section 2.7.

Approach Angle. The angle between the trajectory of a missile and the vertical on approach to the ground.

Arming. Removal of the mechanical and electrical barriers to the operation of the explosive train in a fuze prior to which an activating signal in the fuze cannot cause detonation.

Arming Angle. The angle through which the detonator rotor turns to complete the arming cycle.

Arming Delay. The time delay between launching of the missile to completion of arming. The term sometimes applied to the T-2 delayed arming device. See Section 4.2.

Arming Pulse. An electrical disturbance sometimes arising when the detonator circuit is closed.

Arming Wire. A wire attached to an aircraft which prevents initiation of the arming cycle until the bomb or rocket has left the aircraft.

Audio. An adjective applied to electrical circuits or appropriate signals having frequencies in the audible range. It usually refers to the detected doppler signal.

B Voltage. The supply voltage for the anodes of the electronic tubes.

B Winding. The high voltage winding of the generator.

Bar Type. A transversely excited radio proximity fuze using a center-fed transverse bar as an antenna.

[a] Many of the terms included in this glossary may not occur in the text but occur frequently in the references given in the Bibliography.

BRLG. (Bomb, Radio, Longitudinal, Generator.) An early designation for a generator-powered ring-type bomb fuze.

Brown. A code term for 75 megacycles per second.

BRTB. (Bomb, Radio, Transverse, Battery.) An early designation for a battery-powered bomb fuze with transverse antenna.

BRTG. (Bomb, Radio, Transverse, Generator.) An early designation for a generator-powered radio proximity fuze with transverse antenna.

BTL. Bell Telephone Laboratories, Inc.

Burst Surface. A hypothetical surface surrounding the target, showing the locus of fuze bursts upon approach to the target.

C. Capacitance.

C Bias or Voltage. The supply voltage for biasing the pentode and thyratron.

C or C_v. An abbreviation for C voltage.

Camera Obscura. The usual camera obscura technique applied to observation of fuze function.

Cap. The ring or conical cap used as an exciting antenna.

Carrier. The radio frequency signal generated by the fuze oscillator.

CCM. Counter-countermeasures.

CF. Carrier frequency.

CIMA. Carrier indication of mechanical arming. See Section 8.3.

CM. Countermeasures.

Compensated Load or Resistor. A dummy antenna resistor with inductance to simulate the actual antenna load.

Corncake. The proving ground at Fort Fisher.

Critical Grid Voltage. The maximum bias (negative) at which the thyratron will fire.

D. Dud.

Delayed Arming Device. An auxiliary wind-driven delay mechanism which locks the windmill for a preset distance of air travel. See Section 4.2.

Demagnetizing. Refers to the process of reducing the magnetic pole strength of a generator rotor to the appropriate value.

Detonator. A device which initiates an explosive train in response to an electrical current.

Diode. A two-element electron tube used as the rectifier of the doppler signal.

Diode Impedance. The resistance which, when inserted in series with a perfect diode, would make it behave like an actual diode.

Directivity Pattern. A polar plot of the antenna gain as a function of angle. See $f^2(\theta)$ in Section 2.8.

Doppler Effect. The shift in frequency produced by relative motion between transmitter and receiver.

Doppler Frequency. The difference or shift frequency produced by the doppler effect.

Driver. A term applied to the windmill or turbine used as the prime mover of the generator.

Dud. A fuze which does not function.

Dumping. The discharge of the thyratron plate condenser (in a fuze having RC arming) with insufficient current to fire the detonator. See Section 3.3.6.

E. Early function. Function or operation of the fuze after arming and before reaching the target sometimes, particularly in the case of rockets, confined to the first 5 seconds of flight.

Effective Critical Voltage. The critical voltage of the thyratron in a fuze under operating conditions but in the absence of target signal. See Section 3.3.2.

Electrical Arming. Completion of electrical circuits necessary to produce arming in a bomb fuze. This usually occurs slightly ahead of mechanical arming, in bomb fuzes. In fuze with RC arming, electrical arming occurs *after* mechanical arming.

Emerson. Emerson Radio and Phonograph Corporation.

Feedback Network. The network in an amplifier which returns a portion of the output signal to the amplifier input for controlling the gain frequency characteristic. See Section 3.2.3.

Field Test. A functional test of a fuze on a missile in flight.

Final Test or Final Test Position. Laboratory test or equipment for making the test on the completed electronic subassembly of the fuze. See Section 7.9.

Firing Indicator. A laboratory device (usually comprising a neon lamp) to indicate the firing of the thyratron.

Firing Voltage. The signal input to an amplifier required to fire the thyratron, usually measured in millivolts. Cf. MvF.

FOMA. Function on mechanical arming. See Section 8.3.

Frequency, Audio or Doppler. *See* doppler frequency.

Frequency, Carrier. *See* carrier frequency.

Frequency, Generator. The frequency of the alternating current produced by the generator.

Frequency, Microphonic. The frequency of the microphonic disturbances.

Frequency, Rotational. The rotational frequency of the wind-driven generator system.

Frequency Response Curve. A plot of amplifier gain versus audio frequency, usually plotted on log-log paper.

g. Unit of acceleration; viz., 32.2 feet per second per second.

Gain, Antenna. *See* antenna gain.

Gain, Audio. *See* audio gain.

Gain, Flat. The gain of the audio amplifier with the feedback network disconnected.

Gain, Nonregenerative. *See* gain, flat.

Gain-Frequency Characteristics. *See* frequency response curve.

Gear Train. A speed-reducing train of gears interposed between the windmill and mechanical arming system.

Gimmick. A small variable capacitor composed of twisted insulated wires, used to adjust the amplifier feedback.

Green. The code term for 150 megacycles per second.

Grid Reaction. The variation of grid bias with oscillator load. See Section 3.1.2.

HD. Heard dud. A dud in which the carrier signal of the fuze is observed.

Head-on Doppler. A doppler frequency for head-on approach to an airplane target.

Holding Bias. The excess of the applied thyratron bias over the effective critical voltage.

Hum. The high-frequency audio signal output of the amplifier occurring at generator frequency, and usually due to modulation produced by a-c operation of the filament.

Hum Injection. A portion of the filament voltage injected into the amplifier to cancel the inherent hum. See Section 3.2.3.

Impact Parameter. The perpendicular distance from the missile trajectory to an airplane target.

Impeller. A term sometimes, but inaccurately, applied to a windmill or turbine prime mover generator.

Induction Field. That component of the transmitted electromagnetic field which varies inversely as the square of the distance from the transmitter. See Section 2.10.

Jamming. A countermeasure to produce malfunction of fuzes by radio methods.

L. Late. A fuze function lower than expected from the normal distribution of function heights or (in the case of an antiaircraft fuze) a function beyond a statistically expected burst surface.

Load. Electrical load on an oscillator.

Load Resistor. A resistor used as an equivalent of the antenna load. Cf. compensated resistor and Section 7.2.

Longitudinal. Referring to a fuze system in which the predominant radiating current flows along the axis of the missile.

M. Middle function. A random function occurring more than 5 seconds after launching.

M Wave. The actual audio signal produced by the doppler effect of the target on the fuze. This term is particularly applicable to the nonsinusoidal doppler signal generated in approaching an airplane target. See Sections 2.11 and 2.12.

Mechanical Arming. Removal of the mechanical barrier in the explosive train. In the case of RC arming, it usually implies also the closing of the electrical contacts to initiate the RC arming cycle.

Michigan Sensitivity. The theoretical height at which a fuze would function when approaching ground at optimum velocity with optimum orientation of the missile, usually approximately horizontal.

MRLG. (Mortar, Radio, Longitudinal, Generator.) An early designation for the T-132 mortar fuze.

MROG. (Mortar, Radio, O for loop, Generator.) An early designation for the T-172 mortar fuze.

Mutual Interference. Jamming of one fuze by an-

other in too close proximity. Cf. sympathetic function.

MvF. Cf. firing voltage. Generally used as inverse measure of amplifier gain.

N. Number. Usually referring to number of rounds in a field test.

NBS. National Bureau of Standards.

NDRC. National Defense Research Committee.

NORMAL CRITICAL VOLTAGE. The thyratron critical voltage in the absence of microphonics from the oscillator.

NORMALIZATION. The process of demagnetizing a generator rotor to give correct supply voltages.

OD. Designation for the oscillator-diode type of fuze.

ODD. Ordnance Development Division of the National Bureau of Standards.

OSRD. Office of Scientific Research and Development.

P. Proper function of the fuze on approach to the target.

PEAK GAIN. The maximum gain of an amplifier.

PHILCO. Philco Radio and Television Corporation.

PKMvF. Millivolts to fire at the frequency of peak gain. Cf. MvF.

PLATE REACTION. The variation of the oscillator plate current in response to a change of high-frequency load on the oscillator.

POTATO MASHER. A term applied to the encasing can for generator-powered bomb fuzes. See Figure 18, Chapter 4.

POA. Puff on approach. Refers to spotting charge indication of function on approach to target.

POD. Power-oscillating detector. A type of plate reaction oscillator operating at relatively high power level.

POW. Puff on water. Cf. POA.

PREDICTED HEIGHT. Height of function predicted on the basis of laboratory measurements of overall fuze sensitivity.

PROPELLER. A term used to indicate the externally mounted windmill or driver for the generator.

PULSE TEST. An overall test of a fuze assembly complete except for detonator, indicating that all circuits are functioning.

PURGE PELLET. A pellet of specially rapid burning material to purge the combustion chamber of residual propellant after the burning is essentially complete. See Section 9.2 on afterburning.

Q. A figure of merit for a tuned circuit or a reactor.

QUASI STATIC. The component of the electromagnetic field which varies inversely as the cube of the distance from the transmitter. See Section 2.10.

R. Resistance.

RADIATION FIELD. That component of the transmitted electromagnetic field which varies inversely as the distance from the transmitter. See Section 2.8.

RADIATION LOAD. Radiation resistance. The component of the antenna resistance representing radiation losses.

RADIATION PATTERN. A polar plot of radiation field strength versus angle, $f(\theta)$. See Section 2.8.

RANDOM FUNCTION. A fuze function after arming and before the target is reached.

RC. Resistance-capacitance network or the time constant of such a network used for time delay of electrical arming in some fuze models. See Section 3.3.6.

RAYTHEON. Raytheon Manufacturing Company.

RED. Code designation for 130 megacycles per second.

REFLECTION COEFFICIENT. Ratio of reflected to incident field strength.

REGULATION CIRCUIT. A resistance-capacitance network incorporated in the power supply to maintain an output voltage or voltages essentially independent of generator speed above a limited minimum speed.

RESISTANCE SENSITIVITY. A measure of the differential voltage produced by an oscillator under change of load resistance. See Section 3.1.2.

RGD. Reaction grid detector. Cf. grid reaction.

RING TYPE. A generator-powered fuze in which the antenna consists of a ring surrounding the windmill.

RIPPLE VOLTAGE. *See* hum voltage.

ROA. Radius of action. The maximum radius of a hypothetical burst surface enclosing an airborne target. See also the definition in Section 5.1.3.

ROB. Radio-operated bomb. A very early generic designation of radio proximity fuzes for bombs.

ROR. Radio-operated rocket. Cf. ROB.

ROTOR, DETONATOR. The moving portion of the mechanical barrier to an explosive train (in bomb fuzes).

ROTOR, GENERATOR. The rotating permanent magnet in a generator.

RRLG. (Rocket, Radio, Longitudinal, Generator.) An early designation for generator-powered proximity fuzes for rockets.

SAFE. The condition of a fuze which is not armed.

SD. Self destruction. Destruction of a fuze by operation of a device within the fuze at a predetermined time or distance after launching, presumably after the missile has passed the target. See Sections 4.3.1 and 3.3.8.

SENSITIVITY. *See* resistance sensitivity and Section 3.1.2.

SENSITIVITY PATTERN. A hypothetical surface surrounding a missile representing the locus of target positions for functions.

SERPENTINE. A type of single coil generator winding. See Section 3.4.5.

SETBACK. A term referring to reaction on a fuze or missile caused by acceleration of the projectile.

SIGNAL SIMULATOR. A laboratory device to simulate the signal produced by interaction of the fuze and target. See Section 2.12.

SPIKES. Short duration pulses, usually originating in triode microphonics.

SQUEGGING. The periodic instability of a high-frequency oscillator. See Section 3.1.5.

SQUIB. Colloquial for electric detonator.

SURGE CURRENT. The peak value of a thyratron plate current surge.

SYLVANIA. Sylvania Electric Products Corporation.

SYMPATHETIC FUNCTION. The functioning of a fuze on a spurious target produced by the explosion of another missile.

T. Refers to target function in a field test.

TARGET FACTOR. Reflection coefficient of a ground target multiplied by 100.

TARGET FUNCTION. The proper function of a fuze upon approach to the intended target.

TURBINE. An air-driven turbine used in some models of generator-power fuzes.

VANE. *See* windmill.

VT. The commonly accepted designation for proximity fuze. It is generally understood that the letters stand for "variable time" but they also imply "vacuum tube."

WESTINGHOUSE. Westinghouse Electric Corporation.

WHITE. A code designation for 110 megacycles per second.

WINDMILL. An externally mounted air-driven prime mover.

WURLITZER. The Rudolph Wurlitzer Corporation.

YELLOW. A code designation for 140 megacycles per second.

ZENITH. Zenith Radio Corporation.

ZERO LENGTH LAUNCHER. A launcher for rockets in which the rocket is supported over a negligible portion of its burning period.

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BIBLIOGRAPHY

Numbers such as Div. 4-100-1M indicate that the document listed has been microfilmed and that its title appears in the microfilm index printed in a separate volume. For access to the index volume and to the microfilm, consult the Army or Navy agency listed on the reverse of the half-title page.

Chapter 1

1. "Notes on Conference of 12 August 1940 between representatives of NDRC and BuOrd," by Commander C. Hoover, Aug. 17, 1940. Div. 4-100-M1
2. "Development of Anti-Aircraft Fuzes for Rockets," Initiation of Project, Ordnance Committee Minutes No. 18178, Apr. 24, 1942.
3. "Initiation of Radio Rocket Fuze Project," Ordnance Committee Minutes No. 18364, June 5, 1942.
4. "Initiation of Development Project for T40, T43 Fuzes," Ordnance Committee Minutes No. 19939, Mar. 17, 1943.
5. "Initiation of Development Project for T50, T51, T52 Fuzes," Ordnance Committee Minutes No. 21117, July 17, 1943.
6. "Initiation of Development Project for T6 Fuzes," Ordnance Committee Minutes No. 21681, Sept. 8, 1943.
7. "Initiation of Development Project for T30 Fuzes," Ordnance Committee Minutes No. 25243, Sept. 28, 1943.
8. "Transfer of T82 Fuzes to Army Development," Ordnance Committee Minutes No. 26818, Mar. 1, 1943.
9. "Initiation of Development Project for T32, T2005 Fuzes," Ordnance Committee Minutes No. 27280, Apr. 12, 1945.
10. "Initiation of Development for T132, T171, T172 Fuzes," Ordnance Committee Minutes No. 27427, Apr. 26, 1945.
11. *The Optimum Point of Burst for a 500-lb GP Bomb Equipped with a Proximity Fuze,* by Marston Morse, William R. Transue, Roy Kuebler, TDBS Report 7, Office of the Chief of Ordnance, Apr. 22, 1943.
12. *The Dependence of Optimum Height of Burst of Shells and Bombs upon Angle of Fall, Safety Angle, etc.,* by Marston Morse, William R. Transue, TDBS Report 41, Office of the Chief of Ordnance, Sept. 2, 1944.
13. *Optimum Height of Burst of Fragmentation Bombs and Effect with VT Fuzes,* by Marston Morse, William R. Transue, and M. H. Heins, TDBS Report 58, Office of the Chief of Ordnance, Apr. 3, 1945.
14. *Probable Advantages of VT Fuzes on 81-mm HE Mortar Shell M56 and M43A1,* Marston Morse, William R. Transue, and M. H. Heins, TDBS Report 60, Office of the Chief of Ordnance, Mar. 30, 1945.
15. *A Comparison of Damage Effect of Ground Bursts of 20-lb Bomb with an Air Burst of the 260-lb Bomb and of the 500-lb Bomb against Planes and Revetments,* TDBS Report 61, Office of the Chief of Ordnance, Apr. 24, 1945.
16. *Second Interim Report on Fuze, Bomb, T50,* Report of the Army Air Force Proving Ground Command on Project 4012C4712.82, Apr. 12, 1945.
17. *Supplemental Tests on Aircraft Rockets for Anti-Personnel Effects,* Report of the Army Air Forces Proving Ground Command on Project 4514C471.94, Sept. 4, 1945.
18. *Final Report on Air-to-Air Firing of Mk 171 Mod 0 Fuzes on 3.4" and 5.0" AR,* NOTS Project 104 AFS, Aug. 5, 1945.
19. *Probability that a 4.5" Rocket Fired from Astern Will Destroy a Twin-Engine Bomber (JU-88) as a Function of Point of Burst,* AMP Report 21.1R, Statistical Research Group, Applied Mathematics Panel, July 1944. Div. 4-412.3-M1
20. *Optimum Burst Surface for 4.5" Airborne Rocket Fired from Astern at Twin-Engine Bomber (JU-88),* AMP Report 21.2R, Statistical Research Group, Applied Mathematics Panel, July 1944. Div. 4-412.3-M2
21. *Effectiveness of a 4.5" Airborne Rocket with T5 Fuze When Fired at Twin-Engine Bomber from Astern,* AMP Report 21.3R, Statistical Research Group, Applied Mathematics Panel, July 1944. Div. 4-412.3-M3
22. *Probability of Damage Computations Pertinent to Design of Fuze for 5" AR and 5" HVAR,* Milton Friedman, Informal Study (AMP Study 21, SRG 396), Applied Mathematics Panel, January 1945. Div. 4-412.3-M5
23. *Airburst for Blast Bombs,* E. Bright Wilson, Jr., OSRD 4943, OEMsr-260 and OEMsr-569, Service Projects OD-03, NO-224, *et al.,* Division 2. Report A-322, Princeton University, WHOI, *et al.,* April 1945. Div. 4-242.12-M4
24. *Evaluation of Airburst Bombs for Clearance of Mine Field,* Robert D. Huntoon, OSRD 4100, Service Project OD-27, Report A-291, September 1944. Div. 4-242.12-M1
25. *Effect of Height of Detonation of Bombs on the Blast Pressures and Impulses of Surrounding Buildings, in Richmond Park 1/7 Square Model Town Tests,* Road Research Laboratory, Department of Scientific and Industrial Research Ministry of Supply, Note MOS/434/RJ.EK, March 1945.
26. *Trials with an M64 500-lb Bomb, Nose Initiated, Fuze T50 against Close Support Targets,* B. L. Welch, Appendix to Proceeding Q-2881, Ordnance Board, Dec. 13, 1944.
27. *Note on Airbursts of 4,000-lb HC Bomb with T51*

Fuze, F. H. East, Technical Note ARM343, Royal Aircraft Establishment, April 1946.

28. *Optimum Height of Setting for T50 Fuze on Blast Bombs, A/C LC 500-lb Mark 2 Charged Dyed Methyl Seelicyliate and Dropped onto Jungle*, San Jose, Project Report 69, Chemical Warfare Service, June 22, 1945.
29. *Multiple Bomb Assessment of Blast Bomb A/C LC 500-lb Mark 2 Fitted with T51 Fuze and Charged HT when Dropped from High Altitudes into Jungle Terrain*, San Jose, Project Report 73, Chemical Warfare Service, July 28, 1945.
30. *Interim Report*, February 15 to March 7, 1945, A. V. Astin to Dr. Alexander Ellett.
31. *Fire Bombs Tried at Eglin Field with VT Fuzes*, T. N. White, Report OD-2-255M, NBS, Ordnance Development Division, July 13, 1945. Div. 4-242.13-M2
32. *Operational Uses of Bomb and Rocket VT Fuzes by U. S. Army and Navy in World War II*, Walter G. Finch, Report OD-Army-4, NBS, Ordnance Development Division, Oct. 15, 1945. Div. 4-221-M2
33. Letter to R. C. Tolman. Subject: "The Use in Proximity Fuzes for Rockets of the Various Electronic Components of Small Size for Use in the Proximity Fuze for Antiaircraft Projectiles," W. S. Parsons, May 21, 1942. Div. 4-211.1-M1
34. *Evaluation of Air Burst Bombs for Clearance of Mine Fields*, E. F. Horton, Jr., Final Report on Experimental Investigation, OD-1-599, NBS, Ordnance Development Division, Dec. 23, 1944. Div. 4-242.12-M3

Chapter 2

ARMOR AND ORDNANCE REPORTS OF NDRC

1. *Radio Controlled Antiaircraft Proximity Fuze; The Reflection of Radio Waves from Airplanes*, Robert D. Huntoon, Service Project OD-27, Progress Report A-19, Nov. 10, 1941. Div. 4-211-M1
2. *Radio Proximity Fuzes for Bombs and Rockets as of May 28, 1942*, Harry M. Diamond, Service Projects OD-27, OD-33, and CWS-19, Progress Report A-64, June 15, 1942. Div. 4-211.1-M2
3. *A Device for the Measurement of the Absolute Sensitivity of an End-Fed Axially-Excited Radio Proximity Fuze*, William L. Kraushaar, and Robert D. Huntoon, Service Project OD-27 and OD-26, Report A-143, Feb. 13, 1943. Div. 4-625-M1
4. *Radio Proximity Fuze for Plane-to-Plane Rocket Application*, Harry M. Diamond, W. S. Hinman, Jr., Robert D. Huntoon, Cledo Brunetti, and Chester H. Page, Service Projects OD-27 and OD-26, Report A-144, Feb. 12, 1943. Div. 4-211.1-M3
5. *VT Fuzes for Rockets and Bombs, Training Lectures*, Robert D. Huntoon, Chester H. Page, B. J. Miller, Jacob Rabinow, and Harry M. Diamond, OSRD 5326, Service Projects OD-27, NO-77B, and NO-77R, Report A-334, January 1945. Div. 4-200-M1
6. *Radiation Properties of BRLG*, Robert D. Huntoon, Service Project OD-27, Report 43-R, July 28, 1943. Div. 4-243.11-M1
7. *Design of Special Targets*, Robert D. Huntoon, Service Project OD-27, Report 44-R, May 12, 1943. Div. 4-618-M2
8. *Selection of Optimum Frequencies for BRLG Vehicles*, Robert D. Huntoon, Service Project OD-27, Report 52-R, August 1943. Revised: Apr. 17, 1944. Div. 4-243.11-M2

REPORTS OF ORDNANCE DEVELOPMENT DIVISION OF NATIONAL BUREAU OF STANDARDS

9. *Basic Theory of the Radio Proximity Fuze*, Philip R. Karr, NBS, Ordnance Development Division, May 25, 1945. Div. 4-211-M2
10. *Afterburning from Rocket Motors and Malfunctioning of VT Fuzes* (Summary Report), H. F. Stimson, Report OD-1-896, NBS, Ordnance Development Division, Oct. 15, 1945. Div. 4-411.11-M6
11. *Theoretical Estimates of the Radiation Resistance of the BRTG Propeller Antenna Model*, J. G. Hoffman and David Feldman, Report OD-2-30, NBS, Ordnance Development Division, Apr. 24, 1944. Div. 4-243.21-M2
12. *Prediction of Heights of Function* (Supplement to Report OD-3-89), Bertrand J. Miller and M. Schulkin, Report OD-BE-22R, NBS, Ordnance Development Division, Aug. 11, 1944. Div. 4-241-M3
13. *Electrical Interaction of T-50 Fuzes* (Part II), Bertrand J. Miller, Report OD-BE-42R, NBS, Ordnance Development Division, Sept. 29, 1944. Div. 4-245-M4
14. *Expected Radius of Action for the T-30*, Bertrand J. Miller and Franklin M. Fletcher, Report OD-BE-53R (and Addendum), NBS, Ordnance Development Division, Nov. 11, 1944. Div. 4-241.1-M1
15. *Estimates of Radius of Action of T-30 from Steady State Computations*, R. F. Morrison, Jr., Thomas M. Marion, and Franklin M. Fletcher, Report OD-BE-56R, NBS, Ordnance Development Division, Dec. 4, 1944. Div. 4-241.1-M3
16. *Construction of Apparatus for Measuring Reflection Coefficient*, Otto E. Spokas, Report OD-BE-77R, NBS, Ordnance Development Division, Apr. 23, 1945. Div. 4-624-M3
17. *Measurement of the Reflection Coefficient of the Water Bombing Range at Aberdeen Proving Ground*, Otto E. Spokas, Report OD-7-201R, NBS, Ordnance Development Division, May 1, 1945. Div. 4-624-M4
18. *Striking Angles and Velocities for Level Flight Bombing*, Allen T. Foster, Report OD-7-87R, NBS, Ordnance Development Division, Mar. 20, 1945. Div. 4-311.3-M2
19. *Impact Angles and Striking Velocities for Dive*

[redacted]

Bombing, F. L. Celauro, Report OD-7-88R, NBS, Ordnance Development Division, Mar. 22, 1945. Div. 4-242.14-M1

20. *Striking Angles and Velocities for Level Flight Bombing with the M-65 Bomb*, Allen T. Foster, Report OD-2-223R (Supplement to OD-7-87R), NBS, Ordnance Development Division, June 5, 1945. Div. 4-311.3-M3
21. *Striking Angles and Velocities for Level Flight Bombing with M-57,* Allen T. Foster, Report OD-2-257R (Supplement to OD-7-87R), NBS, Ordnance Development Division, July 18, 1945. Div. 4-311.3-M4
22. *Effect of Ground Reflection on BRLG Performance*, Charles J. Apolenis and Robert D. Huntoon, Report OD-3-19, NBS, Ordnance Development Division, Nov. 2, 1943. Div. 4-243.21-M1
23. *Induction Field Sensitivity*, Chester H. Page, Report OD-3-30, NBS, Ordnance Development Division, Nov. 16, 1943. Div. 4-233-M1
24. *Induction Field of Finite Antennas*, Chester H. Page, Report OD-3-33, NBS, Ordnance Development Division, Nov. 19, 1943. Div. 4-233-M2
25. *Experimental Measurement of the Effect of an Imperfect Reflector on the Induction Field Sensitivity of a Radio-Proximity Fuze*, Otto E. Spokas, Charles C. Gordon, and Robert D. Huntoon, Report OD-3-36, NBS, Ordnance Development Division, Nov. 25, 1943. Div. 4-624-M1
26. *Computation of Heights of Function, Including Induction and Quasi-Static Field Effects*, Bertrand J. Miller and Philip R. Karr, Report OD-3-89, NBS, Ordnance Development Division, Jan. 29, 1944. Div. 4-241-M2
27. *Measurement of the Reflection Coefficient of the New Bombing Range at Aberdeen Proving Ground*, Otto E. Spokas, Report OD-3-90, NBS, Ordnance Development Division, Jan. 29, 1944. Div. 4-624-M2
28. *Radiation Resistance of* [the M-9] *Rocket*, Otto E. Spokas, Charles C. Gordon, and Robert D. Huntoon, Report OD-3-105, NBS, Ordnance Development Division, Mar. 2, 1944. Div. 4-243.22-M1
29. *Microphonic Stability of Oscillator-Diode Type of Fuze Circuit*, Robert D. Huntoon, Report OD-3-117, NBS, Ordnance Development Division, Mar. 22, 1944. Div. 4-238.31-M1
30. *Dummy Antennas*, Robert D. Huntoon, Report OD-3-133, NBS, Ordnance Development Division, Apr. 20, 1944. Div. 4-233-M3
31. *Tuning Compromise for BRLG Units*, Philip R. Karr and Otto E. Spokas, Report OD-3-139, NBS. Ordnance Development Division, May 2, 1944. Revised: June 3, 1944. Div. 4-233.1-M5
32. *Compensated Resistors for Tuning and Loading Standards*, E. Eisner and Paul T. Hawes, Report OD-3-154, NBS, Ordnance Development Division, May 24, 1944. Div. 4-236-M4
33. *Antenna Rings for BRLG*, Philip Krupen, Report OD-3-162, NBS, Ordnance Development Division, June 15, 1944. Div. 4-233-M4
34. *RGD Field Simulator*, Philip Krupen, Report OD-3-163, NBS, Ordnance Development Division, June 17, 1944. Div. 4-238.32-M7
35. *Pole Tests on Various Vehicles at Blossom Point*, James H. Barnard, Glenn L. Scillian, and Ralph Stair, Report OD-3-174, NBS, Ordnance Development Division, Aug. 16, 1944. Div. 4-243.4-M2
36. *Radiation Patterns and Electrical Balance of BRTG*, Glenn L. Scillian and Ralph Stair, Report OD-3-177, NBS, Ordnance Development Division, Aug. 31, 1944. Div. 4-243.11-M5
37. *Radiation Resistance of Zenith BRTG-Z Units*, Glenn L. Scillian and Ralph Stair, Report OD-3-178, NBS, Ordnance Development Division, Sept. 13, 1944. Div. 4-243.21-M4
38. *Resonant Loading of BRTG Units by Test Boxes*, Ralph Stair, Glenn L. Scillian, and Leonard C. Pochop, Report OD-3-196, NBS, Ordnance Development Division, Nov. 13, 1944. Div. 4-233.1-M7
39. *Transparent Charts for Prediction of Function Height*, Philip R. Karr, Chris Gregory, R. B. Schwartz, and M. L. Scott, Report OD-3-257, NBS, Ordnance Development Division, June 6, 1945. Div. 4-241-M7
40. *Low Frequency Operation of Bomb Fuzes*, R. B. Schwartz, Report OD-3-258, NBS, Ordnance Development Division, June 7, 1945. Div. 4-243.11-M11
41. *Computation of Burst Heights of Longitudinally-Excited Bomb Fuzes*, R. B. Schwartz, Report OD-3-281, NBS, Ordnance Development Division, Aug. 7, 1945. Div. 4-241-M8
42. *Early Functions of the MC-382 Radio-Operated Plane-to-Plane Rocket Fuze*, Bertrand J. Miller and Robert D. Huntoon, Progress Report OD-3-AB2, NBS, Ordnance Development Division, June 8, 1943. Div. 4-222.128-M12

MEMORANDA OF ORDNANCE DEVELOPMENT DIVISION OF NATIONAL BUREAU OF STANDARDS

43. *Amplifier Shaping and After-Burning Pulses*, Memorandum to Robert D. Huntoon from Bertrand J. Miller, NBS, Ordnance Development Division, Mar. 4, 1943. Div. 4-238.212-M1
44. *After-Burning and Amplifier Shaping*, Memorandum to W. S. Hinman, Jr., from Robert D. Huntoon, NBS, Ordnance Development Division, Mar. 5, 1943. Div. 4-238.212-M2
45. *After-Burning*, Memorandum to W. S. Hinman, Jr., from Robert D. Huntoon, NBS, Ordnance Development Division, Mar. 18, 1943. Div. 4-411.11-M1
46. *Pole Tests on British Two-Ton Vehicle*, Memorandum to A. V. Astin from Ralph Stair and James

[redacted]

H. Barnard, Memorandum OD-3-33M, NBS, Ordnance Development Division, Aug. 24, 1944. Div. 4-243.4-M3

47. *Radiation Patterns on Zenith and Westinghouse, BRTG*, Memorandum to A. V. Astin from Ralph Stair Memorandum OD-3-34M, NBS, Ordnance Development Division, Aug. 24, 1944. Div. 4-243.11-M3

48. *Computation of Expected Radius of Action*, Memorandum to Harry M. Diamond from Chester H. Page, Memorandum OD-3-53M, NBS, Ordnance Development Division, Nov. 6, 1944. Div. 4-241.1-M2

49. *Radiation Resistance of BRLG Vehicles*, Memorandum to Harry M. Diamond from Robert D. Huntoon, Memorandum OD-BE-2M, NBS, Ordnance Development Division, June 20, 1944. Div. 4-243.21-M3

50. *Electrical Properties of British 4,000-lb Bomb*, Memorandum to Alexander Ellett from Harry M. Diamond, Memorandum OD-BE-42M, NBS, Ordnance Development Division, Aug. 26, 1944. Div. 4-243.11-M4

51. *Mutual Interaction in BRLG Units Dropped in Close Spaced Train*, Memorandum to Harry M. Diamond from Bertrand J. Miller, Memorandum OD-BE-44M, NBS, Ordnance Development Division, Sept. 11, 1944. Div. 4-245-M3

52. *Radiation Properties of British 4,000-lb Bomb*, Memorandum to Harry M. Diamond from Franklin M. Fletcher and Otto E. Spokas, Memorandum OD-BE-47M, NBS, Ordnance Development Division, Sept. 9, 1944. Div. 4-243.11-M6

53. *Interaction Factors for BRLG Units*, Memorandum to Harry M. Diamond from Franklin M. Fletcher, Memorandum OD-BE-48M, NBS, Ordnance Development Division, Sept. 11, 1944. Div. 4-245-M2

54. *Radiation Properties of HVAR 5″ Rocket*, Memorandum to Harry M. Diamond from Otto E. Spokas and R. F. Morrison, Jr., Memorandum OD-BE-50M, NBS, Ordnance Development Division, Sept. 13, 1944. Div. 4-243.22-M2

55. *Radiation Properties of Depth Bombs*, Memorandum to Harry M. Diamond from Otto E. Spokas and Franklin M. Fletcher, Memorandum OD-BE-53M, NBS, Ordnance Development Division, Sept. 15, 1944. Div. 4-243.11-M7

56. *Radiation Properties of M43 and M56*, Memorandum to Harry M. Diamond from Otto E. Spokas and Franklin M. Fletcher, Memorandum OD-BE-54M, NBS, Ordnance Development Division, Sept. 18, 1944. Div. 4-243.13-M1

57. *Additional Measurements on Radiation Properties of the British 4,000-lb Bomb* (Supplement to OD-BE-47M), Memorandum to Harry M. Diamond from Otto E. Spokas and Franklin M. Fletcher, Memorandum OD-BE-56M, NBS, Ordnance Development Division, Sept. 19, 1944. Div. 4-243.11-M8

58. *Radiation Properties of 1,000 and 2,000-lb GP Bombs*, Memorandum to Harry M. Diamond from Otto E. Spokas and Franklin M. Fletcher, Memorandum OD-BE-59M, NBS, Ordnance Development Division, Sept. 27, 1944. Div. 4-243.11-M9

59. *Radiation Properties of the 5-inch Mattress and the 155 mm Mortar Projectile*, Memorandum to Harry M. Diamond from Otto E. Spokas and Franklin M. Fletcher, Memorandum OD-BE-63M, NBS, Ordnance Development Division, Sept. 30, 1944. Div. 4-243.13-M2

60. *Radiation Properties of Vehicles M30, M64, and M81*, Memorandum to Harry M. Diamond from Franklin M. Fletcher and Otto E. Spokas, Memorandum OD-BE-66M, NBS, Ordnance Development Division, Oct. 5, 1944. Div. 4-243.11-M10

61. *Calculations Concerning Radius of Action in Plane-to-Plane Application*, Memorandum to Harry M. Diamond from Bertrand J. Miller, Memorandum OD-BE-82M, Nov. 14, 1944. Div. 4-412.4-M4

62. *Radiation Properties of Gas Tanks*, Memorandum to Harry M. Diamond from Bertrand J. Miller, Preliminary Memorandum OD-BE-89M, NBS, Ordnance Development Division, Nov. 27, 1944. Div. 4-243.3-M1

63. *Radiation Properties of Various Rockets*, Memorandum to Harry M. Diamond from Bertrand J. Miller, Memorandum OD-BE-92M, NBS, Ordnance Development Division, Dec. 12, 1944. Div. 4-243.22-M3

64. *Radiation Resistance of the M56 Mortar, the M43 Mortar with an M56 Tail, the AN-M41 Fragmentation Bomb and the 155 mm Chemical Mortar Projectile When Used with an MRLG Type Unit*, Memorandum to Harry M. Diamond from Otto E. Spokas, Memorandum OD-BE-98M, NBS, Ordnance Development Division, Dec. 19, 1944. Div. 4-243.23-M1

65. *The Effect of Various Antenna Rings on the Radiation Resistance of the M56 Mortar and the M43 Mortar with the M56 Tail*, Memorandum to Harry M. Diamond from Otto E. Spokas, Memorandum OD-BE-127M, NBS, Ordnance Development Division, Apr. 2, 1945. Div. 4-243.23-M2

66. *Additional Radiation Resistance Data on the HVAR, AR3.5 and AR5 Rockets*, Memorandum to Harry M. Diamond from Otto E. Spokas, Memorandum OD-7-202M, NBS, Ordnance Development Division, May 1, 1945. Div. 4-243.22-M4

67. *Radiation Resistance Presented to the Type T-2005 Unit*, Memorandum to Harry M. Diamond from Otto E. Spokas, Memorandum OD-7-205M, NBS, Ordnance Development Division, June 25, 1945. Div. 4-243.22-M5

68. *Radiation Patterns of the AR and H4.5 Rocket*, Memorandum to Harry M. Diamond from Otto E. Spokas, Memorandum OD-7-212M, NBS, Ordnance Development Division, July 21, 1945. Div. 4-243.12-M2

69. *Radiation Resistance of the M-56 Mortar Shell with 2" Tail Extension,* Memorandum to Harry M. Diamond from Otto E. Spokas, Memorandum OD-7-213M, NBS, Ordnance Development Division, Aug. 28, 1945. Div. 4-243.23-M3
70. *Revision and Extension of OD-OAG-20 (Striking Velocity, Striking Angle, Vertical Component of Striking Velocity vs Altitude),* Memorandum to Recipients of OD-OAG-20 from D. Fisher, OD-OAG-41, NBS, Ordnance Development Division, Sept. 11, 1944.
71. *Tables of Doppler Frequency vs Altitude of Release at 200 Miles Per Hour for Carrier Frequencies,* D. Fisher, Report OD-OAG-42, NBS, Ordnance Development Division, Sept. 19, 1944. Div. 4-412.4-M2
72. *Summary of Ballistic Data for the Mk-7, CIT Rocket,* Memorandum to Harry M. Diamond from F. A. Ransom, Memorandum OD-OAG-45, NBS, Ordnance Development Division, Sept. 28, 1944. Div. 4-412.4-M3
73. *Navy Rocket Trajectory Analysis,* Memorandum to T. N. White from A. L. Leiner (in collaboration with D. C. Friedman), Memorandum OD-2-203, NBS, Ordnance Development Division, May 5, 1945. Div. 4-412.1-M8
74. *Table of Bomb Velocity vs Air Travel,* Allen T. Foster, Report OD-2-252M, NBS, Ordnance Development Division, July 5, 1945. Div. 4-242.14-M2
75. *Striking Angles and Vertical Components of Striking Velocities of Rockets Fired from an Airplane in Dive.* Memorandum to T. N. White from F. L. Celauro, Memorandum OD-2-261M, NBS, Ordnance Development Division, July 25, 1945. Div. 4-412.4-M6

REPORTS OF CONTRACTORS OF DIVISION 4 OF NDRC

76. *Research and Development Conducted by Philco Corporation on P4-772 Radio Proximity Fuze for Large Bombs* (Final Report), R. A. Bell, OEMsr-866, Symbol 2164, Philco Radio and Television Corporation, June 15, 1943. Div. 4-211.1-M4
77. *Considerations of the Problem of Adapting the Radio Proximity Fuze to the M-56 Mortar Projectile,* Alfred S. Khouri, University of Florida, Oct. 30, 1943. Div. 4-211.23-M1
78. *A Study of the Possibility of Making Both the Loop and Longitudinal Type Fuzes from the Basic University of Florida MROG Unit,* Alfred S. Khouri, University of Florida, Apr. 3, 1945. Div. 4-211.23-M5
79. *Modifications of the MROG to Reduce the Loop Area and Prominence of the Loop,* Alfred S. Khouri, University of Florida, Mar. 29, 1945.
80. *Mortimer Loop Radio Proximity Fuze Report,* University of Florida, Apr. 22, 1944. Div. 4-211.23-M2
81. *Interaction of Loop Antenna and Neighboring Conductors with Special Reference to the MROG Fuze,* R. C. Williamson, Report WRL-UF-3 University of Florida, Aug. 10, 1944. Div. 4-233-M5
82. *A Possible Method of Reducing the Undesired Parasitic Radiation from a Vehicle Excited Transversely,* C. Albert Moreno, University of Florida, Nov. 1, 1943. Div. 4-243.4-M1
83. *Performance of the Basic MROG Design Adapted to End-Fed Longitudinal Excitation,* Alfred S. Khouri, University of Florida, Apr. 12, 1945.
84. *Final Technical Report on Generator-Powered Proximity Fuzes for Bombs,* K. D. Smith and A. L. Stillwell, OEMsr-905, Bell Telephone Laboratories, May 30, 1944. Div. 4-211.21-M5
85. *Generator Report,* R. N. Harmon, Westinghouse Electric and Manufacturing Company, Apr. 8, 1943. Div. 4-232.2-M2
86. *Development of a Ground Approach Proximity Bomb Nose Fuze, BRTG,* T. M. Bloomer, OEMsr-343 and OEMsr-1106, Termination Report CFE-760, Westinghouse Electric and Manufacturing Company, Apr. 28, 1945. Div. 4-211.21-M11
87. *Proximity Fuze, Bomb, Nose, Ground Approach, Type VT, T-82,* T. M. Bloomer, OEMsr-343 and OEMsr-1106, Termination Report CFE-759, Westinghouse Electric and Manufacturing Company, Apr. 28, 1945. Div. 4-222.113-M2
88. *Proximity Fuze—Hornet,* John R. Boykin, OEMsr-343, Termination Report CFE-762, Westinghouse Electric and Manufacturing Company, Apr. 28, 1945. Div. 4-211.1-M6
89. *Proximity Fuze [for the] Plane-to-Plane Rocket, Type POD,* John R. Boykin, OEMsr-343, Termination Report CFE-761, Westinghouse Electric and Manufacturing Company, Apr. 28, 1945. Div. 4-211.1-M5
90. *BRLG Proximity Fuzes* (Final Report), F. H. Osborne, OEMsr-1161 and OEMsr-1163, Rudolph Wurlitzer Company, Mar. 15, 1945. Div. 4-211.22-M1
91. *Generator-Powered Radio Proximity Fuze for Bombs—Transverse Antenna Type,* Earl J. Diehl, OSRD 5111, OEMsr-980 and OEMsr-1133, Service Projects OD-27 and NO-77B, Final Report A-326, Zenith Radio Corporation, Mar. 30, 1945. Div. 4-211.21-M10

REPORTS OF OTHER DIVISIONS OF NDRC

92. *Repeater Jamming of Radio Proximity Fuzes,* Russell Yost, Jr., and Walter E. Tolles, OEMsr-1305, Service Projects SC-98.07 and NA-109, Division 15 Report 1305-26, Jan. 27, 1946. Div. 4-246-M1

BRITISH REPORTS

93. *Reflections from Bodies,* N. F. Mott, Apr. 24, 1941.

UNCLASSIFIED TECHNICAL PUBLICATIONS

94. "Circuit Relations in Radiating Systems and Applications to Antenna Problems," P. S. Carter, *Proceedings of the Institute of Radio Engineers,* Vol. 20, No. 6, June 1932, pp. 1004-1041.
95. "The Reciprocal Energy Theorem," J. R. Carson, *Bell System Technical Journal,* Vol. 9, April 1930, pp. 325-331.

Chapter 3

ARMOR AND ORDNANCE REPORTS OF NDRC

1. *Radio Controlled Antiaircraft Proximity Fuze: The Reflection of Radio Waves from Airplanes,* Robert D. Huntoon; based on cooperative work by Harry M. Diamond, W. S. Hinman, Jr., Robert D. Huntoon, Cledo Brunetti, and Chester H. Page, Service Project OD-27, Progress Report A-19, Nov. 10, 1941. Div. 4-211-M1
2. *The Performance of Small Dry Batteries When Subjected to Low Temperatures and the Effect of Heating the Batteries Internally by Alternating Current Supplied to the Battery Terminals,* John P. Schrodt, D. Norman Craig, and George W. Vinal, Service Project OD-27, Progress Report A-30, Jan. 20, 1942. Div. 4-232.1-M1
3. *The National Bureau of Standards Battery for Low Temperature Operation,* John P. Schrodt, D. Norman Craig, and George W. Vinal, Service Project OD-27, Progress Report A-49, May 2, 1942. Div. 4-232.1-M2
4. *The Possibility of a Generator Power Supply for Proximity Fuzes,* Allen S. Clarke, Service Projects OD-27 and OD-33, Progress Report A-62M, Dec. 15, 1942. Div. 4-232.2-M1
5. *Radio Proximity Fuzes for Bombs and Rockets as of May 28, 1942,* Harry M. Diamond, Service Projects OD-27, OD-33, and CWS-19, Progress Report A-64, June 12, 1942. Div. 4-211.1-M2
6. *Firing of Squibs by Condenser Discharge—Energy Losses in Thyratrons,* Evert G. Bennett and Richard K. Cook, Service Projects OD-27 and OD-33, Progress Report A-65, June 25, 1942. Div. 4-231.1-M1
7. *Circuit Design of the Ultra-High Frequency Unit for the Radio Proximity Fuze,* Chester H. Page, Service Projects OD-27 and OD-33, Progress Report A-80, Aug. 11, 1942. Div. 4-211.2-M1
8. *Characteristics of Small Thyratrons for Use in Proximity Fuzes,* Mahlon F. Peck, Service Projects OD-27 and OD-33, Progress Report A-112, Nov. 10, 1942. Div. 4-231.1-M4
9. *Analysis of the Feedback Amplifier for MC-382 Fuze,* Robert D. Huntoon, William L. Kraushaar, and Herbert D. Cook, Progress Report A-122, Dec. 7, 1942. Div. 4-238.222-M1
10. *A Device for the Measurement of the Absolute Sensitivity of an End-Fed Axially-Excited Radio Proximity Fuze,* William L. Kraushaar and Robert D. Huntoon, Service Projects OD-27 and OD-26, Report A-143, Feb. 11, 1943. Div. 4-625-M1
11. *Radio Proximity Fuze for Plane-to-Plane Rocket Application,* Harry M. Diamond, W. S. Hinman, Jr., Robert D. Huntoon, Cledo Brunetti, and Chester H. Page, Service Projects OD-27 and OD-26, Report A-144, Feb. 12, 1943. Div. 4-211.1-M3
12. *Generator Powered Radio Proximity Fuze for Bombs; Transverse Antenna Type,* Earl J. Diehl, OSRD 5111, OEMsr-980 and OEMsr-1133, Service Projects OD-27 and NO-77B, Final Report A-326, Zenith Radio Corporation, Mar. 30, 1945. Div. 4-211.21-M10
13. *Pilot Production of T-50 Fuzes,* Allen S. Clarke and C. N. Julian, OSRD 5351, OEMsr-1227, Service Projects OD-27, NO-77B, and NO-77R, Report A-335, Bowen and Company, Inc., Apr. 12, 1945. Div. 4-222.111-M3
14. *A Radio Proximity Fuze: Type MROG,* OSRD 5412, OEMsr-949, Service Project OD-27, Report A-338, War Research Laboratory, University of Florida, April 1945. Div. 4-211.23-M3
15. *Specification for Rectifier Bridge Assembly RA-1,* NBS, Ordnance Development Division, July 5, 1944. Div. 4-235-M6
16. *Specification of Generator G-1,* NBS, Ordnance Development Division, Dec. 9, 1944. Div. 4-232.2-M20
17. *Specification of Power Supply PS-1 and PS-2,* NBS, Ordnance Development Division, Dec. 9, 1944. Div. 4-232.2-21

NDRC ENGINEERING REPORTS

18. *Status Report on Design of Generator-Powered Radio Fuze,* Chester H. Page and F. Stanley Atchison, Service Projects OD-27 and SC-40, Engineering Report 1-R, May 29, 1943. Div. 4-211.2-M2
19. *Status of Generator Development,* George V. Morris, Service Project OD-27, Engineering Report 3-R, Zenith Radio Corporation, May 27, 1943. Div. 4-232.2-M6
20. *Preliminary Discussion of Amplifier Simplification For MC-382 Fuze,* R. H. Pintell, Service Project OD-27, Memorandum Report 35-R, Emerson Radio and Phonograph Corporation, Apr. 8, 1943. Div. 4-238.222-M2
21. *Status of Generator Development,* R. N. Harmon, Service Project OD-27, Memorandum Report 38-R, Westinghouse Electric and Manufacturing Company, Apr. 8, 1943. Div. 4-232.2-M3
22. *Generator Regulation,* Chester H. Page, Service Project OD-27, Memorandum Report 40-R, Apr. 26, 1943. Div. 4-232.2-M4
23. *Amplifier Specifications for MC-382 Fuze,* R. H. Pintell, Service Project OD-27, Parts I and II, Memorandum Report 48-R, Emerson Radio and Phonograph Corporation, May 24 and July 24, 1943. Div. 4-238.222-M3

REPORT OF ORDNANCE DEVELOPMENT DIVISION OF NATIONAL BUREAU OF STANDARDS

24. *Leakage Resistance of BS-4 and BS-5 Detonators,* W. A. Yates, Report OD-1-75, NBS, Ordnance Development Division, Dec. 4, 1943. Div. 4-238.523-M1

[redacted]

25. *BS-4 Detonators Fired through Sylvania SA-782-B Thyratrons, Summary Report on Recent Tests*, G. Singer and T. N. White, Report OD-1-82, NBS, Ordnance Development Division, Dec. 21, 1943. Div. 4-238.521-M6
26. *Time Lags in BS-4 Detonators When Fired without Firing Condensers*, L. C. Miller, Report OD-1-154, NBS, Ordnance Development Division, Feb. 15, 1944. Div. 4-238.521-M8
27. *BRLG Generator Speeds for Several Combinations of Vehicle, Propeller Lead, and Manufacturer*, D. C. Friedman, Report OD-1-256 and 256A (Supplement), NBS, Ordnance Development Division, May 22, 1944 and June 6, 1944. Div. 4-232.2-M14 (Supp.), Div. 4-232.2-M13
28. *Field Test—27 Philco T50E1 with Metal Propellers (PX-5)*, D. A. Worcester and D. C. Friedman, Report OD-1-405, NBS, Ordnance Development Division, July 17, 1944. Div. 4-222.111-M1
29. *Field Test—40 Bowen T50E10 Units Lot 141 (CB-420)*, E. F. Horton and R. Vorkink, Report OD-1-585, NBS, Ordnance Development Division, Dec. 14, 1944. Div. 4-222.111-M2
30. *Field Test—21 Zenith T51 Units, Lot 53, (CB-430)*, D. A. Worcester and G. Rabinow, Report OD-1-626, NBS, Ordnance Development Division, Jan. 19, 1945. Div. 4-222.112-M1
31. *Field Test—Philco T50E1 Reporters with Doughnut Arming Ring*, D. W. Scott, Report OD-1-660, NBS, Ordnance Development Division, Feb. 22, 1945. Div. 4-222.127-M2
32. *Lot Quality Test of 12 Philco T-30 Units (TBG-95)*, R. G. Tobey and G. Rabinow, Report OD-1-664, NBS, Ordnance Development Division, Mar. 2, 1945. Div. 4-222.124-M2
33. *High Altitude Test, 24 Zenith T-51 Units (CB-457)*, D. A. Worcester and G. Rabinow, Report OD-1-684, NBS, Ordnance Development Division, Mar. 24, 1945. Div. 4-222.112-M2
34. *BS-5 Detonators Fired with 1.5 Microfarad Condenser*, Charles C. Gordon, Report OD-1-699, NBS, Ordnance Development Division, Apr. 2, 1945. Div. 4-238.522-M3
35. *High Altitude Test—12 Zenith T-51 Units (CB-464)*, D. A. Worcester and G. Rabinow, Report OD-1-701, NBS, Ordnance Development Division, Apr. 12, 1945. Div. 4-222.112-M3
36. *Arming Test—18 Westinghouse T-82 Units (CB-474)*, D. A. Worcester and G. Rabinow, Report OD-1-715, NBS, Ordnance Development Division, Apr. 19, 1945. Div. 4-222.113-M1
37. *Field Test—20 Westinghouse T-82 Units (CB-473)*, D. A. Worcester and R. Vorkink, Report OD-1-733, NBS, Ordnance Development Division, May 8, 1945. Div. 4-222.113-M3
38. *Field Test—20 Westinghouse T-82 Units (CB-479)*, D. A. Worcester and R. Vorkink, Report OD-1-736, NBS, Ordnance Development Division, May 8, 1945. Div. 4-222.113-M4
39. *Field Test—21 Zenith T-51 Units (CB-481)*, R. Vorkink, Report OD-1-749, NBS, Ordnance Development Division, May 18, 1945. Div. 4-222.112-M4
40. *Field Test—18 Emerson T-92 Units (CB-482)*, D. A. Worcester and R. Vorkink, Report OD-1-755, NBS, Ordnance Development Division, May 21, 1945. Div. 4-222.114-M1
41. *73—Globe Union T-132 (CHP-43)*, R. G. Tobey and D. C. Friedman, Report OD-1-763, NBS, Ordnance Development Division, June 4, 1945. Div. 4-222.131-M3
42. *Reporter Test—10 Westinghouse T-82E1 Units (BX-12)*, D. A. Worcester and G. Rabinow, Report OD-1-879, NBS, Ordnance Development Division, Aug. 28, 1945. Div. 4-222.113-M5
43. *A Two-Stage Feedback Amplifier*, Ralph Stair, Thomas M. Marion, and E. Eisner, Report OD-2-6, NBS, Ordnance Development Division, Nov. 24, 1943. Div. 4-238.227-M1
44. *Regulation with Non-Linear Resistors in Series with Load Current*, J. G. Hoffman, Report OD-2-7, NBS, Ordnance Development Division, Jan. 1, 1944. Div. 4-236-M2
45. *Investigation of Design Features of Westinghouse MK Generators*, J. G. Reid, Jr., and Charles Ravitsky, Report OD-2-20, NBS, Ordnance Development Division, Feb. 23, 1944. Div. 4-232.2-M12
46. *Two-Tube Amplifier for BRTG-P4B Audio Amplifier*, Ralph Stair and Thomas M. Marion, Report OD-2-33, NBS, Ordnance Development Division, May 13, 1944. Div. 4-238.226-M1
47. *BRTG-P4C Amplifier*, Ralph Stair and Thomas M. Marion, Report OD-2-38, NBS, Ordnance Development Division, June 7, 1944. Div. 4-238.226-M2
48. *Arming of VT Bomb Fuzes*, A. L. Leiner, Report OD-2-275, NBS, Ordnance Development Division, Sept. 15, 1945. Div. 4-244.1-M3
49. *Pentode Acceptance Amplifier*, Robert D. Huntoon, Report OD-BE-1, NBS, Ordnance Development Division, June 19, 1944. Div. 4-238.227-M3
50. *Comparison of Radiated Power of OD and RGD Oscillators*, R. F. Morrison, Jr., Report OD-BE-7R, NBS, Ordnance Development Division, July 17, 1944. Div. 4-238.3-M2
51. *Comparison of OD and RGD Circuits*, R. B. Schwartz, Report OD-BE-13R, NBS, Ordnance Development Division, July 29, 1944. Div. 4-238.3-M3
52. *Voltage Relationships in the RGD Oscillator*, R. F. Morrison, Jr., Report OD-BE-30R, NBS, Ordnance Development Division, Aug. 23, 1944. Div. 4-238.32-M9
53. *Measurement of BRTG Sensitivity*, R. F. Morrison, Jr., Report OD-BE-39R, NBS, Ordnance Development Division, Sept. 18, 1944. Div. 4-625-M2
54. *Delay of 10-E Amplifier*, R. B. Schwartz, Report

[redacted]

OD-BE-41R, NBS, Ordnance Development Division, Sept. 25, 1944. Div. 4-238.223-M3

55. *A High Gain Amplifier Employing a Twin Triode Tube*, Thomas M. Marion, Report OD-BE-47R, NBS, Ordnance Development Division, Oct. 18, 1944. Div. 4-231.3-M3
56. *Probability Distribution of Arming Time Using RC Arming*, Charles Ravitsky, Report OD-BE-49R, NBS, Ordnance Development Division, Oct. 23, 1944. Div. 4-238.514-M3
57. *Analysis of the BS4 Detonator*, Charles Ravitsky, Report OD-BE-73R, NBS, Ordnance Development Division, Mar. 7, 1945. Div. 4-238.521-M9
58. *The Detonator Circuit*, Charles Ravitsky, Report OD-BE-74R, NBS, Ordnance Development Division, Mar. 7, 1945. Div. 4-238.523-M4
59. *Measurement of Firing Voltage*, Robert D. Huntoon, NBS, Ordnance Development Division, Aug. 20, 1943. Div. 4-621-M2
60. *Gain Control for Amplifiers*, Robert D. Huntoon and F. Lamar Cooke, NBS, Ordnance Development Division, Aug. 23, 1943. Div. 4-238.211-M1
61. *Preliminary Information on Audio Amplifier for BRLG-10*, Robert D. Huntoon and F. Lamar Cooke, NBS, Ordnance Development Division, Sept. 18, 1943. Div. 4-238.222-M4
62. *Status Report on Rectifier Sub Group*, F. Stanley Atchison, Report OD-3-I, NBS, Ordnance Development Division, Aug. 11, 1943. Div. 4-235-M1
63. *Tolerances on Complete BRLG-8*, Robert D. Huntoon, Report OD-3-6a, NBS, Ordnance Development Division, Oct. 22, 1943. Div. 4-211.21-M1
64. *Performance of Westinghouse AQ Copper Oxide Rectifying Cells*, F. Stanley Atchison, Report OD-3-VII, NBS, Ordnance Development Division, Aug. 24, 1943. Div. 4-235-M2
65. *Effect of Static Characteristics of Rectifier Cells on A and B Voltages*, F. Stanley Atchison, Report OD-3-IX, NBS, Ordnance Development Division, Sept. 15, 1943. Div. 4-235-M3
66. *Critical Grid Voltage of Thyratron and Hum Voltage Output of BRLG-11*, F. Lamar Cooke, Report OD-3-9, NBS, Ordnance Development Division, Oct. 27, 1943. Div. 4-231.1-M7
67. *Methods of Measuring the Critical Voltage of Thyratrons*, F. Lamar Cooke, Report OD-3-13, NBS, Ordnance Development Division, Nov. 9, 1943. Div. 4-231.1-M8
68. *Generator Performance*, William L. Kraushaar, Report OD-3-17, NBS, Ordnance Development Division, Nov. 1, 1943. Div. 4-232.2-M8
69. *Performance of Power Supply at High and Low Temperatures*, F. Stanley Atchison, Report OD-3-23, NBS, Ordnance Development Division, Nov. 6, 1943. Div. 4-232.2-M9
70. *BRLG-11A Amplifier for Zell Manufacture*, Robert D. Huntoon, Report OD-3-24, NBS, Ordnance Development Division, Nov. 8, 1943. Div. 4-238.224-M1
71. *Amplifier Performance of BRLG-8 Potted with Glidden Compound*, Albert Weiss, Report OD-3-26, Nov. 8, 1943, and OD-3-26a, Nov. 18, 1943, NBS, Ordnance Development Division, Nov. 8, 1943. Div. 4-239.1-M4
72. *Experiments with Standard MC-382 Fuzes Converted to Reaction Type Fuzes with Grid Detection (RGD Fuze)*, Philip Krupen and W. S. Hinman, Jr., Report OD-3-27, NBS, Ordnance Development Division, Nov. 15, 1943. Div. 4-238.32-M1
73. *Discussion of Proposed Rectifier Specifications*, F. Stanley Atchison, Report OD-3-28, NBS, Ordnance Development Division, Nov. 6, 1943. Div. 4-235-M5
74. *Preliminary Report on Tuning and Loading Devices for BRLG*, Paul E. Landis, Report OD-3-37, NBS, Ordnance Development Division, Nov. 29, 1943. Div. 4-233.1-M1
75. *New Amplifier Design*, Robert D. Huntoon, Report OD-3-38, NBS, Ordnance Development Division, Nov. 29, 1943. Div. 4-238.213-M1
76. *Component Specifications for BRLG-11A*, Robert D. Huntoon, Report OD-3-39, NBS, Ordnance Development Division, Dec. 2, 1943. Div. 4-238.224-M2
77. *Design and Tolerance Curves for BRLG-11A*, F. Lamar Cooke and Robert D. Huntoon, Report OD-3-40, NBS, Ordnance Development Division, Dec. 3, 1943. Div. 4-238.224-M3
78. *Effect of Component Tolerances on Performance of BRLG-11A*, Robert D. Huntoon, Report OD-3-46, NBS, Ordnance Development Division, Dec. 7, 1943. Div. 4-238.224-M4
79. *Report on Status of Work on RGD*, Bertrand J. Miller, Report OD-3-47, NBS, Ordnance Development Division, Dec. 7, 1943. Div. 4-238.32-M2
80. *Experiments with the RGD Circuit, Applied to BRLG-8*, William L. Kraushaar, Report OD-3-48, NBS, Ordnance Development Division, Dec. 9, 1943. Div. 4-238.32-M3
81. *Status of BRLG Production Designs*, W. S. Hinman, Jr., Report OD-3-57, NBS, Ordnance Development Division, Dec. 16, 1943. Div. 4-211.21-M3
82. *Effect of Tolerances in the Regulation Network*, William L. Kraushaar, Report OD-3-60, NBS, Ordnance Development Division, Dec. 17, 1943. Div. 4-232.2-M10
83. *Performance of Zell 11A Amplifiers on Standard Test Voltages*, Robert D. Huntoon, Report OD-3-63, NBS, Ordnance Development Division, Dec. 23, 1943. Div. 4-238.224-M5
84. *Arming Considerations in T6*, Bertrand J. Miller and Philip R. Karr, Report OD-3-74, NBS, Ordnance Development Division, Jan. 22, 1944. Div. 4-238.515-M1
85. *An RGD Circuit for the MC-382*, Philip Krupen, Report OD-3-79, NBS, Ordnance Development Division, Jan. 15, 1944. Div. 4-238.32-M4
86. *BRLG-10A*, F. Lamar Cooke, Report OD-3-94,

[redacted]

NBS, Ordnance Development Division, Feb. 3, 1944. Div. 4-238.227-M2

87. *Arming Resistor for T5,* Robert D. Huntoon, Report OD-3-101, NBS, Ordnance Development Division, Feb. 22, 1944. Div. 4-236-M3

88. *RGD Circuit for BRLG Applications,* Philip Krupen, Report OD-3-102, NBS, Ordnance Development Division, Feb. 24, 1944. Div. 4-238.32-M5

89. *Amplifier Characteristics for T6 Application,* Charles J. Apolenis and Robert D. Huntoon, Report OD-3-107, NBS, Ordnance Development Division, Mar. 7, 1944. Div. 4-238.225-M1

90. *Microphonic Stability of the Oscillator-Diode Type of Fuze Circuit,* Robert D. Huntoon, Report OD-3-117, NBS, Ordnance Development Division, Mar. 22, 1944. Div. 4-238.31-M1

91. *Dummy Antennas,* Robert D. Huntoon, Report OD-3-133, NBS, Ordnance Development Division, Apr. 20, 1944. Div. 4-233-M3

92. *MRLG Apex Firing and Generator Regulation,* Chester H. Page, Report OD-3-142, NBS, Ordnance Development Division, May 9, 1944. Div. 4-512-M1

93. *Linearity of 11A Amplifier,* George Nordquist, Report OD-3-148, NBS, Ordnance Development Division, May 13, 1944. Div. 4-238.224-M6

94. *Uniformity of Raytheon Triodes in RGD,* Chester H. Page, Report OD-3-149, NBS, Ordnance Development Division, May 13, 1944. Div. 4-231.3-M1

95. *Triode Microphonics,* Robert D. Huntoon, Bertrand J. Miller, and R. B. Schwartz, Report OD-3-153, NBS, Ordnance Development Division, May 20, 1944. Div. 4-231.3-M2

96. *Behavior of the 11A Amplifier at 5,000 CPS,* Philip R. Karr and George Nordquist, Report OD-3-156, NBS, Ordnance Development Division, May 25, 1944. Div. 4-238.224-M7

97. *Amplifier Hum Suppression,* Robert D. Huntoon, and Philip R. Karr, Report OD-3-158, NBS, Ordnance Development Division, June 9, 1944. Div. 4-238.213-M2

98. *Voltage Speed Regulation of Zenith Generators,* Morris Brenner and Ralph L. Ueberall, Report OD-3-167, NBS, Ordnance Development Division, July 1, 1944. Div. 4-232.2-M15

99. *Effect of Low Temperature and High Voltage on Performance of 11A Amplifier,* Philip R. Karr and Milton Weiss, Report OD-3-169, NBS, Ordnance Development Division, July 19, 1944. Div. 4-238.224-M8

100. *10E Amplifier,* Philip R. Karr and Chester H. Page, Report OD-3-170, NBS, Ordnance Development Division, July 21, 1944. Div. 4-238.223-M1

101. *Effect of Amplifier Shape on Function Height of T50 E10,* Philip R. Karr, Report OD-3-172, NBS, Ordnance Development Division, Aug. 11, 1944. Div. 4-238.223-M2

102. *Effect of Potting Upon Amplifier Shaping,* Philip R. Karr and George Nordquist, Report OD-3-175, NBS, Ordnance Development Division, Aug. 17, 1944. Div. 4-239.1-M5

103. *Component Tolerance Study on BRTG-P5 Amplifier,* Chris Gregory and Ralph Stair, Report OD-3-180, NBS, Ordnance Development Division, Sept. 22, 1944. Div. 4-238.226-M3

104. *Effect of Low Plate Supply Voltage on RGD-PB Units,* Philip Krupen and Leonard C. Pochop, Report OD-3-184, NBS, Ordnance Development Division, Oct. 6, 1944. Div. 4-238.32-M10

105. *Universal High Gain Amplifier,* George Nordquist, Report OD-3-186, NBS, Ordnance Development Division, Oct. 20, 1944. Div. 4-238.211-M3

106. *The Performance of Zenith BRTG-Z Units as Function of Supply Voltages,* Lawrence J. Diou and Ralph Stair, Report OD-3-189, NBS, Ordnance Development Division, Oct. 27, 1944. Div. 4-621-M3

107. *Tube and Component Study of 10E Amplifier,* Chris Gregory, Report OD-3-190, NBS, Ordnance Development Division, Oct. 30, 1944. Div. 4-238.223-M4

108. *Test of Four Types of Power Supplies and Generators (Quam Nichols, Utah, Knapp-Monarch and Wurlitzer),* Ralph L. Ueberall, Report OD-3-193, NBS, Ordnance Development Division, Nov. 9, 1944. Div. 4-232.2-M18

109. *Experimental Production of High Gain Modified White Amplifiers,* Philip R. Karr, Report OD-3-194, NBS, Ordnance Development Division, Nov. 8, 1944. Div. 4-238.211-M4

110. *Use of Off-Tolerance Condensers in the 10E Amplifier,* George Nordquist, Report OD-3-195, NBS, Ordnance Development Division, Nov. 11, 1944. Div. 4-237-M5

111. *Sensitivity of BRTG-POD,* Glenn L. Scillian and Chester H. Page, Report OD-3-199, NBS, Ordnance Development Division, Nov. 17, 1944. Div. 4-238.31-M2

112. *Alteration of Feedback Components in the Basic 10E Circuit,* George Nordquist, Report OD-3-200, NBS, Ordnance Development Division, Nov. 18, 1944. Div. 4-238.223-M5

113. *Electrical Design Considerations for T-30,* William E. Kraushaar, R. B. Schwartz, and Bertrand J. Miller, Report OD-3-203, NBS, Ordnance Development Division, Dec. 5, 1944. Div. 4-241-M4

114. *The BRTG-T1B Amplifier,* Ralph Stair and Glenn L. Scillian, Report OD-3-204, NBS, Ordnance Development Division, Dec. 7, 1944. Div. 4-238.225-M2

115. *Proposed Amplifier for T-30 (Air-to-Ground, Air-to-Air),* Philip R. Karr, Report OD-3-205, NBS, Ordnance Development Division, Dec. 12, 1944. Div. 4-238.225-M3

116. *The 11-N2 Medium Band Amplifier,* George Nordquist, Report OD-3-208, NBS, Ordnance Development Division, Jan. 8, 1945. Div. 4-238.227-M4

117. *Plate Voltage Fluctuations of Generator Power Supplies,* James H. Barnard, Leonard C. Pochop,

and Ralph Stair, Report OD-3-210, NBS, Ordnance Development Division, Jan. 22, 1945. Div. 4-232.2-M22

118. *An RGD Oscillator for Working into High Radiation Resistances,* Richard F. Mills, Report OD-3-212, NBS, Ordnance Development Division, Jan. 24, 1945. Div. 4-238.32-M11

119. *Use of T-30 Filter with Wurlitzer Generator,* Chester H. Page, Report OD-3-214, NBS, Ordnance Development Division, Jan. 31, 1945. Div. 4-237-M6

120. *T-50 Function Height for Various Amplifiers under Manifold Release Conditions,* Mary L. Scott, Report OD-3-215, NBS, Ordnance Development Division, Feb. 2, 1945. Div. 4-241-M5

121. *A Simplified RGD-PB Oscillator,* Paul Miller, Report OD-3-216, NBS, Ordnance Development Division, Feb. 7, 1945. Div. 4-238.32-M12

122. *Revised Circuit for BRTG-T1B Amplifier,* Dorothy R. Adams and George Nordquist, Report OD-3-219, NBS, Ordnance Development Division, Mar. 2, 1945. Div. 4-238.225-M5

123. *The T-132 (mortar fuze) Apex Performance Problem,* William L. Kraushaar, Report OD-3-220, NBS, Ordnance Development Division, Mar. 3, 1945. Div. 4-222.131-M2

124. *Selection of Screen Grid Voltage Divider for MRLG-1, T-132, in Connection with the Apex Firing Problem,* George Nordquist, Report OD-3-221, NBS, Ordnance Development Division, Mar. 10, 1945. Div. 4-512-M2

125. *Temperature Coefficient of Allen-Bradley, Erie, Continental Carbon ⅓ Watt Resistors, and IRC ¼ Watt Resistors,* F. W. Jirauch, Report OD-3-222, NBS, Ordnance Development Division, Mar. 2, 1945. Div. 4-236-M11

126. *Frequency Modulation in Generators,* Ralph Stair and Glenn L. Scillian, Report OD-3-223P, NBS, Ordnance Development Division, Mar. 12, 1945. Div. 4-232.2-M23

127. *Suggested Amplifier for T-132L Having Low Gain at Low Frequency,* George Nordquist, Report OD-3-225, NBS, Ordnance Development Division, Mar. 12, 1945. Div. 4-238.225-M6

127a. *The RGD Oscillator,* Philip Krupen, Report OD-3-227, NBS, Ordnance Development Division, Mar. 14, 1945. Div. 4-238.32-M13

128. *The Effect of Tube Parameters on the Available Gain of Amplifiers,* Chris Gregory, Report OD-3-231, NBS, Ordnance Development Division, Mar. 17, 1945. Div. 4-238.211-M5

129. *A Quasi-Hartley Plate-Loaded RGD Oscillator,* Paul Miller and Richard F. Mills, Report OD-3-232, NBS, Ordnance Development Division, Mar. 20, 1945. Div. 4-238.32-M14

130. *Preliminary Report on Heights of Function with Proposed Universal Amplifier for Mortar Application,* Philip R. Karr, Mary L. Scott, and George Nordquist, Report OD-3-235P, NBS, Ordnance Development Division, Apr. 4, 1945. Div. 4-241-M6

131. *Addendum to OD-3-235P,* George Nordquist, April 16, 1945. Div. 4-241-M6

132. *Comparison of Wire-Wound and Ceramic Gain Controls for Use in the 10E Amplifier,* F. W. Jirauch and Donald G. Green, Preliminary Report OD-3-236P, NBS, Ordnance Development Division, Apr. 7, 1945. Div. 4-238.211-M6

133. *Apex Performance of the T-171 Mortar Fuze with RC Arming Delay,* Philip Krupen, Report OD-3-242, NBS, Ordnance Development Division, May 5, 1945. Div. 4-238.514-M4

134. *Thyratron Normal Critical Voltages for Various Amplifiers,* George Nordquist, Report OD-3-249, NBS, Ordnance Development Division, May 24, 1945. Div. 4-231.1-M11

135. *Temperature Effect on G-U T-132 Amplifiers and Amplifier Components,* F. W. Jirauch and Donald G. Green, Preliminary Report OD-3-252P, NBS, Ordnance Development Division, May 28, 1945. Div. 4-238.225-M8

136. *Response of Shaped Amplifiers to Step Pulses and Sharp Pulses,* Philip R. Karr, R. B. Schwartz, and Mary L. Scott, Report OD-3-253, NBS, Ordnance Development Division, May 31, 1945. Div. 4-238.212-M4

137. *Pentode Input Impedance,* George Nordquist, Report OD-3-254, NBS, Ordnance Development Division, May 31, 1945. Div. 4-231.4-M12

138. *Temperature Characteristics of the Ceramic Condensers in the Globe-Union T-132 Amplifier,* F. W. Jirauch, Report OD-3-255P, NBS, Ordnance Development Division, June 4, 1945. Div. 4-237-M9

139. *Grid Bias Circuit for T-171 Mortar Fuze to Reduce Apex Malfunction,* George Nordquist and Dorothy R. Adams, Report OD-3-256, NBS, Ordnance Development Division, June 5, 1945. Div. 4-238.514-M5

140. *Transparent Charts for Prediction of Function Height,* Philip R. Karr, Chris Gregory, R. B. Schwartz, and Mary L. Scott, Report OD-3-257, NBS, Ordnance Development Division, June 6, 1945. Div. 4-241-M7

141. *Revised T-2005 Amplifier,* Dorothy R. Adams, Report OD-3-264, NBS, Ordnance Development Division, July 30, 1945. Div. 4-238.225-M9

142. *A Study of Some Amplifier Curves for Use with the M43C Mortar,* Mary L. Scott and George Nordquist, Report OD-3-267P, NBS, Ordnance Development Division, July 4, 1945. Div. 4-238.213-M3

143. *Correlation of Rotor Magnetic Characteristics with Generator Output,* Glenn L. Scillian and Ralph L. Ueberall, Report OD-3-269, NBS, Ordnance Development Division, July 5, 1945. Div. 4-232.22-M9

144. *Effect of Key Components on Amplifier Response Characteristics,* George Nordquist, Report OD-3-

275, NBS, Ordnance Development Division, July 16, 1945. Div. 4-238.213-M4

145. *Air Speed-Generator Output Regulation for Mortar Shell Fuzes,* Glenn L. Scillian and L. M. Andrews, Report OD-3-278, NBS, Ordnance Development Division, July 20, 1945. Div. 4-232.2-M25

146. *Arming Pulse Protection Circuit.* Philip R. Karr, William L. Kraushaar, and Chester H. Page, Report OD-3-284, NBS, Ordnance Development Division, Sept. 14, 1945. Div. 4-238.515-M6

147. *Effect of Different Regulation Networks on T-132 Generator Speeds,* Glenn L. Scillian, Report OD-3-286, NBS, Ordnance Development Division, Sept. 14, 1945. Div. 4-232.2-M26

148. *Generator Voltage Measurements,* F. Manov and Jacob Rabinow, Report OD-4-1, NBS, Ordnance Development Division, Aug. 13, 1943. Div. 4-621-M1

149. *Absolute Frictional Torque of Generator Bearings,* A. Chartock and L. B. Heilprin, Report OD-4-7, NBS, Ordnance Development Division, Nov. 29, 1943. Div. 4-232.23-M1

150. *Speed Regulating Propellers,* Jacob Rabinow, Report OD-4-11, NBS, Ordnance Development Division, Dec. 4, 1943. Div. 4-232.21-M1

151. *Specification of Maximum Starting Torque of Complete BRLG Unit,* A. Chartock and L. B. Heilprin, Report OD-4-13, NBS, Ordnance Development Division, Dec. 6, 1943. Div. 4-211.21-M2

152. *Propeller Torque at Low Velocity,* L. M. Andrews, Report OD-4-19, NBS, Ordnance Development Division, Dec. 21, 1945. Div. 4-232.21-M3

153. *Bursting Speed of Generator Rotors,* Samuel Kolodny, Report OD-4-6, NBS, Ordnance Development Division, Feb. 23, 1944. Div. 4-232.22-M4

154. *Measurement of Dynamic Propeller Unbalance,* E. U. Rotor and L. G. Koontz, Report OD-4-43, NBS, Ordnance Development Division, Mar. 23, 1944. Div. 4-232.21-M5

155. *Comparative Speeds of Brass and Bakelite Propellers* (Supp. 1), Louis Schuman, Report OD-4-45, NBS, Ordnance Development Division, Apr. 6, 1944. Div. 4-232.21-M6

156. *Propeller Unbalance Tester* (3 supplements), Jacob Rabinow, Report OD-4-48, NBS, Ordnance Development Division, Apr. 20, 1944. Div. 4-616-M1

157. *Torque Developed by 2"x12" RRLG Propellers,* Samuel Kolodny, Report OD-4-51, NBS, Ordnance Development Division, Apr. 19, 1944. Div. 4-232.21-M7

158. *Speed Tests of Stamped Brass and Duralumin Propellers* (3 supplements), Louis Schuman, Report OD-4-60, NBS, Ordnance Development Division, May 22, 1944. Div. 4-232.21-M8

159. *Life Test on Oilite Bearings of MRLG Units,* A. Chartock, Report OD-4-74, NBS, Ordnance Development Division, June 16, 1944. Div. 4-232.23-M3

160. *Determination of Static Thrust Load Limit for the ½ Inch New Departure R-3 Ball Bearing,* A. Chartock, Report OD-4-83, NBS, Ordnance Development Division, Sept. 19, 1944. Div. 4-232.23-M4

161. *The Use of Precision Bearings in BRLG and T-50 Noses,* Jacob Rabinow, Report OD-4-88, NBS, Ordnance Development Division, Dec. 14, 1944. Div. 4-232.23-M6

162. *Fifty Indiana Steel and Arnold Engineering Rotors Submitted for Test by Bowen and Company,* Samuel Kolodny, Report OD-4-97, NBS, Ordnance Development Division, Mar. 2, 1945. Div. 4-232.22-M6

163. *Effect of Condenser Leakage on RC Arming,* Cledo Brunetti, Report OD-5-126, NBS, Ordnance Development Division, Sept. 23, 1943. Div. 4-238.514-M1

164. *Noise Performance of Raytheon Diodes,* M. Schulkin, Report OD-5-224, NBS, Ordnance Development Division, Dec. 7, 1943. Div. 4-231.2-M1

165. *Surge Current Performance and Requirements of BRLG Filter Condensers,* Willis E. Armstrong, Report OD-5-594, NBS, Ordnance Development Division, Sept. 13, 1944. Div. 4-237-M3

166. *Minimum Capacity Requirements for the BRLG Filter Condensers,* Willis E. Armstrong, Report OD-5-655, NBS, Ordnance Development Division, Oct. 10, 1944. Div. 4-237-M4

167. *Revised Amplifier for T-91,* Paul E. Landis and George Nordquist, Report OD-5-765, NBS, Ordnance Development Division, Mar. 29, 1945. Div. 4-238.225-M7

168. *Change in T-91 Amplifier to Obtain a Longer Trimmer Condenser,* Cledo Brunetti and George Nordquist, Report OD-5-769, NBS, Ordnance Development Division, Apr. 2, 1945. Div. 4-237-M8

169. *RF Sensitivity for the Zenith T-172 Unit and Variations Thereof,* Otto E. Spokas, Report OD-7-214R, NBS, Ordnance Development Division, Aug. 13, 1945. Div. 4-233-M6

MEMORANDA OF ORDNANCE DEVELOPMENT DIVISION OF NATIONAL BUREAU OF STANDARDS

170. *Tests on Reliability of Firing, Minimum Reliable Firing Voltage and Time Lags for BS-5 Squibs,* W. A. Yates, Memorandum PG-319, NBS, Ordnance Development Division, Sept. 30, 1942. Div. 4-238.522-M1

171. *Specification Tests on BS-4 Squibs,* W. A. Yates, Memorandum PG-380, NBS, Ordnance Development Division, Nov. 6, 1942. Div. 4-238.521-M1

172. *Reliability of Firing BS-4 Squibs and Time Tests with Radio Frequency Choke and with Resistance in Series with Squib,* Allen V. Astin and W. A. Yates, Memorandum PG-383, NBS, Ordnance Development Division, Nov. 9, 1942. Div. 4-238.521-M2

[redacted]

173. *Test on Minimum Firing Current of BS-4 Squib*, W. A. Yates, Memorandum PG-395, NBS, Ordnance Development Division, Nov. 18, 1942. Div. 4-238.521-M3

174. *Reliability of Firing and Time Test on SA782B, Sylvania Thyratrons*, W. A. Yates, Memorandum PG-412, NBS, Ordnance Development Division, Dec. 2, 1942. Div. 4-231.11-M1

175. *Time Lag Specification for BS-4 Squibs*, Allen V. Astin and W. A. Yates, Service Project OD-27, Memorandum Report 29-T, NBS, Ordnance Development Division, Jan. 29, 1943. Div. 4-238.521-M4

176. *Minimum Voltage to Fire BS-4 Detonators through Thyratrons in Complete MC-382 Heads*, Memorandum from Theodore B. Godfrey to Harry M. Diamond, by L. C. Miller, NBS, Ordnance Development Division, Dec. 30, 1943. Div. 4-238.521-M7

177. *Firing Circuit Curves*, Memorandum from Theodore B. Godfrey to Messrs. Diamond, Astin, *et al.*, NBS, Ordnance Development Division, July 26, 1944. Div. 4-238.523-M2

178. Detonator Firing Test, Memorandum from W. A. Yates to Cledo Brunetti, NBS, Ordnance Development Division, Nov. 3, 1944. Div. 4-238.522-M2

179. *Arming Considerations for HVAR*, Bertrand J. Miller, Memorandum OD-BE-17M, NBS, Ordnance Development Division, July 12, 1944. Div. 4-244.2-M1

180. *Amplifier with Hum-Bucking for White RGD*, Philip R. Karr, Memorandum OD-3-28M, NBS, Ordnance Development Division, Aug. 8, 1944. Div. 4-238.32-M8

181. *Incorporation of RC Arming for T-30*, William L. Kraushaar, Memorandum OD-3-48M, NBS, Ordnance Development Division, Oct. 20, 1944. Div. 4-238.514-M2

182. *Temperature Coefficient of Condensers Used in the 10-E Amplifier*, F. Jirauch, Memorandum OD-3-86M, NBS, Ordnance Development Division, Feb. 24, 1945. Div. 4-237-M7

183. *Modification of T-30 Amplifier*, George Nordquist, Memorandum OD-3-88M, NBS, Ordnance Development Division, Mar. 2, 1945. Div. 4-238.225-M4

184. *Possible Uses of Non-Linear Resistors*, Philip Krupen, Memorandum OD-3-99M, NBS, Ordnance Development Division, May 15, 1945. Div. 4-236-M12

185. *Revision of Westinghouse T-82*, Dorothy R. Adams, George Nordquist, and Ralph Stair, Memorandum OD-3-122M, NBS, Ordnance Development Division, Aug. 3, 1945. Div. 4-238.225-M10

186. *Report on Visit to Emerson Company*, Memorandum to W. S. Hinman, Jr., from Philip Krupen, NBS, Ordnance Development Division, Apr. 22, 1943. Div. 4-238.7-M1

187. *Study of Pintell Circuit*, Memorandum to W. S. Hinman, Jr., from Philip Krupen and F. L. Cooke, NBS, Ordnance Development Division, Apr. 30, 1943. Div. 4-238.7-M2

188. *Request for Laboratory Tests on Performance of BS-4 Squibs*, Memorandum from Cledo Brunetti to Theodore B. Godfrey, NBS, Ordnance Development Division, Oct. 18, 1943. Div. 4-238.521-M5

189. *Relation of Thyratron Repeated Surge Performance to Time Delay*, Abraham Silverstein, Report OD-CT-M8, NBS, Ordnance Development Division, Oct. 4, 1944. Div. 4-231.1-M9

REPORTS OF CONTRACTORS OF DIVISION 4 OF NDRC

190. *Summary of Activities in Development and Pilot Manufacturing Run of Radio Fuses and Accessories*, Vernon D. Hauck, OEMsr-258, Friez Instrument Division, Bendix Aviation Corporation, Sept. 27, 1944. Div. 4-100-M4

191. *Preliminary Draft of Final Technical Report under Contracts OEMsr-885 and OEMsr-1113*, Emerson Radio and Phonograph Corporation, May 14, 1945. Div. 4-100-M6

192. *Final Report of the Federal Telephone and Radio Corporation*, T. Smith Taylor, OEMsr-941, Federal Telephone and Radio Corporation, Oct. 5, 1943. Div. 4-235-M4

193. *A Radio Proximity Fuze, Type BRTD* (Part I), OEMsr-949, University of Florida, Sept. 26, 1945. Div. 4-211.21-M13

194. *Generator Powered Radio Proximity Fuze, Type T-2005*, Muriel E. Pottasch, OEMsr-1437, General Instrument Corporation, Aug. 1, 1945. Div. 4-222.125-M2

195. *Generator Powered Radio Proximity Fuze for Mortars, Longitudinal Excitation Type*, Alfred S. Khouri, OEMsr-1117, Globe-Union, Inc., Sept. 30, 1945. Div. 4-222.131-M6

196. *Summary Technical Report for Contract OEMsr-769*, OEMsr-769, State University of Iowa, Sept. 29, 1945. Div. 4-100-M7

197. [Alnico Rotor Generators], *Final Report on Contract OEMsr-1134*, C. W. Clemons, OEMsr-1134, Knapp-Monarch Company, Nov. 20, 1944. Div. 4-232.2-M19

198. [Generators], *Final Report on NDRC Contract OEMsr-981*, C. W. Clemons, OEMsr-981, Knapp-Monarch Company, Feb. 17, 1944. Div. 4-232.2-M11

199. *Final Report (Reserve Battery and Low Temperature Dry Cells)*, F. T. Bowditch and A. K. Huntley, OEMsr-528, National Carbon Company, Oct. 26, 1944. Div. 4-232.1-M9

    199a. *Final Report of Research and Development Conducted by Philco Corporation on P4-772 Radio Proximity Fuze for Large Bombs*, R. A. Bell, OEMsr-866, Philco Radio and Television Corporation, June 15, 1943. Div. 4-211.1-M4

[redacted]

200. *Final Progress Report Contract OEMsr-1196,* Maurice E. Swift, OEMsr-1196, Philco Radio and Television Corporation, May 31, 1945. Div. 4-211.21-M12

201. [Vacuum Tubes, Types NR-2 (2B-24), NR-3 (2C-27) and NR-5 (2E-27)], *Final Summary Report* [on] *Contract OEMsr-566,* A. Abate, OEMsr-566, Raytheon Manufacturing Company, Oct. 1, 1945. Div. 4-231-M5

202. [Electronic Tubes], *Final Report* [on] *Contract OEMsr-630,* OEMsr-630, Sylvania Electric Products, Inc., 1945. Div. 4-231-M4

203. [Battery Requirements for Project K-4], *Final Technical Report of Work Performed under OEMsr-887,* C. B. Pear, Jr., Washington Institute of Technology, Feb. 17, 1944. Div. 4-232.1-M8

204. *Final Technical Report on Generator Powered Proximity Fuzes for Bombs,* Contract II, K. D. Smith and A. L. Stillwell, OEMsr-905, Western Electric Company and Bell Telephone Laboratories, May 30, 1944. Div. 4-211.21-M5

205. *Development of a Ground Approach Proximity Fuze for Bomb Nose, BRTG,* T. M. Bloomer, OEMsr-343 and OEMsr-1106, Termination Report CFE-760, Westinghouse Electric and Manufacturing Company, Apr. 28, 1945. Div. 4-211.21-M11

206. *Proximity Fuze, Bomb, Nose, Ground Approach; Type VT, T-32,* T. M. Bloomer, OEMsr-343 and OEMsr-1106, Termination Report CFE-759, Westinghouse Electric and Manufacturing Company, Apr. 28, 1945. Div. 4-222.113-M2

207. *RRLG Proximity Fuzes* (Final Report), F. H. Osborne, OEMsr-1161 and OEMsr-1163, Rudolph Wurlitzer Company, Mar. 15, 1945. Div. 4-211.22-M1

208. *Final Technical Report of Work Performed under Contract OEMsr-954,* OEMsr-954, Zell Corporation, Jan. 12, 1945. Div. 4-100-M5

209. *Mass Production of T-51 Fuzes by the Zenith Radio Corporation,* Earl J. Diehl, OEMsr-1477, Service Project OD-27, Zenith Radio Corporation, Oct. 30, 1945. Div. 4-222.112-M5

210. *Generator-Powered Radio Proximity Fuze for Mortars: Loop Transverse-Antenna Type,* Earl J. Diehl, OEMsr-1477, Service Project OD-27, Zenith Radio Corporation, Oct. 30, 1945. Div. 4-222.132-M1

211. *Development Report—1 5/16" Diameter Generator for Fuze Well,* George V. Morris, OEMsr-980, Zenith Radio Corporation, Oct. 8, 1943. Div. 4-232.2-M7

UNITED STATES MILITARY PUBLICATIONS

212. U. S. Army Ordnance Department Tentative Specification AXS-1199, February 10, 1944, Detonator, Electric, T3.

213. U. S. Army Signal Corps Specification 371-2088, Nov. 19, 1943, Electron Tube 2D29 (Thyratron).

UNCLASSIFIED TECHNICAL PUBLICATIONS

214. "An Alternating Current Dynamo with a Flat Characteristic for Bicycle Illumination," H. A. G. Hazeu and M. Kiek, *Phillips Technical Review,* Vol. III, No. 3, p. 87, March 1938.

215. Circular C448 of the National Bureau of Standards, "Permanent Magnets," Raymond L. Sanford, Aug. 10, 1944.

216. "Selenium Rectifier Characteristics, Application and Design Factors," C. A. Clarke, *Electrical Communication,* Vol. 20, No. 1, 1941.

217. *Radio Engineers Handbook,* Frederick E. Terman, McGraw-Hill Book Co., New York.

Chapter 4

REPORTS OF ORDNANCE DEVELOPMENT DIVISION OF NATIONAL BUREAU OF STANDARDS

1. *Six Speed Regulating Propellers on BRLG Self-Reporters (Test Request WBM-9), Aberdeen, December 1, 1943,* D. C. Friedman, Report OD-1-76, NBS, Ordnance Development Division, Dec. 11, 1943. Div. 4-232.21-M2

2. *Six Speed Regulating Propellers on Self-Reporters (WBM-10), Aberdeen, January 23, 1944,* D. C. Friedman, Report OD-1-126, NBS, Ordnance Development Division, Jan. 31, 1944. Div. 4-232.21-M4

3. *Noise Produced by Gear Trains Using Various Types of Planetary Gears,* P. S. Manov, Report OD-4-3, NBS, Ordnance Development Division, Oct. 2, 1943. Div. 4-238.512-M1

4. *Speed Regulating Propellers,* Jacob Rabinow, Report OD-4-11, NBS, Ordnance Development Division, Dec. 4, 1943. Div. 4-232.21-M1

5. *Comparison of Generator Rotor Unbalance and the Measured Eccentricity,* A. Donald Arsem, Report OD-4-70, NBS, Ordnance Development Division, Dec. 27, 1943. Div. 4-232.22-M3

6. *Report on Mechanical Vibration of the BRLG Units Mounted on M-64 Bomb,* Jacob Rabinow, Report OD-4-32, NBS, Ordnance Development Division, Feb. 12, 1944. Div. 4-622-M1

7. *SW-200 Switch Modified to Fire on Contact,* Jacob Rabinow, Report OD-4-44, NBS, Ordnance Development Division, Mar. 31, 1944. Div. 4-238.511-M4

8. *Propeller Unbalance Tester,* Jacob Rabinow, Report OD-4-48, NBS, Ordnance Development Division, Apr. 20, 1944. Div. 4-616-M1

9. *Equipment for Balancing Propellers,* Jacob Rabinow and A. Donald Arsem, Report OD-4-48 Supplement, NBS, Ordnance Development Division, May 19, 1944. Div. 4-616-M2

10. *Air Travel Required for Release of Arming Cover,* E. U. Rotor, Report OD-4-54, NBS, Ordnance Development Division, Apr. 29, 1944. Div. 4-244.1-M1

11. *Turbine Dynamometer for Determining Input*

Torque of Gear Trains, Jacob Rabinow and Louis Schuman, Report OD-4-63, NBS, Ordnance Development Division, May 10, 1944. Div. 4-612-M1

12. *Force Required to Pull Out Arming Wire on BRLG Unit,* Samuel Kolodny, Report OD-4-72, NBS, Ordnance Development Division, June 13, 1944. Div. 4-238.513-M1
13. *Measurement of Vibration Amplitude of MRLG Units,* A. Chartock, Report OD-4-73, NBS, Ordnance Development Division, June 14, 1944. Div. 4-232.22-M5
14. *Life Test on Oilite Bearings of MRLG Units,* A. Chartock, Report OD-4-74, NBS, Ordnance Development Division, June 16, 1944. Div. 4-232.23-M3
15. *Improvements in the Arming System for the T-50 Fuze,* Jacob Rabinow, Report OD-4-79, NBS, Ordnance Development Division, Aug. 23, 1944. Div. 4-238.513-M2
16. *Effect of Generator End Play on Electrical Noise Output,* Louis Schuman and A. Donald Arsem, Report OD-4-81, NBS, Ordnance Development Division, Sept. 7, 1944. Div. 4-232.2-M16
17. *The Use of Precision Bearings in BRLG and T-50 Noses,* Jacob Rabinow, Report OD-4-88, NBS, Ordnance Development Division, Dec. 14, 1944. Div. 4-232.23-M6
18. *Effect of Varying Blade Length and Cover Openings on Speed Characteristics and Air Thrust on Turbine Wheel TFA6070,* Louis Schuman, Report OD-4-91, NBS, Ordnance Development Division, Dec. 29, 1944. Div. 4-232.21-M14
19. *Design of Impact Detonating Element for T-32 Fuze,* Louis Schuman, Report OD-4-96, NBS, Ordnance Development Division, Feb. 17, 1945. Div. 4-238.523-M3
20. *Supporting the T-132 and T-32 Generator to Take Setback,* Louis Schuman, Report OD-4-101, NBS, Ordnance Development Division, Mar. 15, 1945. Div. 4-232.2-M24
21. *Torsion Wire Dynamometer,* Louis Schuman, Report OD-4-105, NBS, Ordnance Development Division, May 26, 1945. Div. 4-612-M2
22. *Proposed Design for Dynamic Balancing Machine,* Jacob Rabinow, Report OD-4-108, NBS, Ordnance Development Division, June 6, 1945. Div. 4-616-M8
23. *Method of Assembling Detonators to the T-132/T-171 Interrupter Rotors,* Jacob Rabinow, Report OD-4-124, NBS, Ordnance Development Division, Aug. 3, 1945. Div. 4-238.523-M5
24. *Second Test of Double-Element Setback Pins,* George T. Parish, Report OD-4-128, NBS, Ordnance Development Division, Sept. 5, 1945. Div. 4-238.513-M4
25. *Nitrided Bearings,* Ermo Furlani and Jacob Rabinow, Report OD-4-132, NBS, Ordnance Development Division, Nov. 6, 1945. Div. 4-232.23-M9

MEMORANDA OF ORDNANCE DEVELOPMENT DIVISION OF BUREAU OF STANDARDS

26. *Setback Switches,* Memorandum to Alexander Ellett from William B. McLean, Jacob Rabinow, and L. M. Andrews, NBS, Ordnance Development Division, Mar. 9, 1942. Div. 4-238.511-M1
27. *Direction of Rotation of Escapement Wheel in Setback Arming Devices,* Memorandum to Alexander Ellett from William B. McLean, NBS, Ordnance Development Division, Oct. 10, 1942. Div. 4-238.511-M3
28. *Rubber Mounted Generator Rotors,* Memorandum to Harry M. Diamond from William B. McLean, NBS, Ordnance Development Division, Sept. 1, 1943. Div. 1-232.22-M1
29. *Contact Springs in the BRLG Rotor Housing,* Memorandum to Harry M. Diamond from William B. McLean, NBS, Ordnance Development Division, Oct. 8, 1943. Div. 4-232.22-M2
30. *Installation of Oilite Bearings in BRLG Generators,* Memorandum to Harry M. Diamond from William B. McLean, NBS, Ordnance Development Division, May 4, 1944. Div. 4-232.23-M2
31. *MRLG Gear Design,* Memorandum to William B. McLean from Jacob Rabinow, NBS, Ordnance Development Division, May 22, 1944. Div. 4-238.515-M3
32. *Calibration of Propeller Unbalance Tester,* Memorandum to William B. McLean from A. Donald Arsem, NBS, Ordnance Development Division, June 30, 1944. Div. 4-616-M3
33. *Measurement of Gain of Balancing Equipment (Propeller),* Memorandum to Jacob Rabinow from A. Donald Arsem, NBS, Ordnance Development Division, July 10, 1944. Div. 4-238.211-M2
34. *Propeller Unbalance Specifications,* Memorandum to Harry M. Diamond from Jacob Rabinow, NBS, Ordnance Development Division, Oct. 16, 1944. Div. 4-616-M4
35. *Metal Propeller with Fluted Blades,* Memorandum to Harry M. Diamond from Jacob Rabinow, NBS, Ordnance Development Division, Nov. 1, 1944. Div. 4-232.21-M13
36. *Coupling Shaft in Front Bearing Assemblies,* Memorandum to Harry M. Diamond from Jacob Rabinow, NBS, Ordnance Development Division, Nov. 13, 1944. Div. 4-232.23-M5
37. *Visit to New Departure, January 5, 1945,* Jacob Rabinow, Memorandum OD-4-11M, NBS, Ordnance Development Division, Jan. 11, 1945. Div. 4-232.23-M7
38. *Lock Washers,* Jacob Rabinow, Memorandum OD-4-12M, NBS, Ordnance Development Division, Jan. 12, 1945. Div. 4-239.2-M1
39. *Some Comments of Field Personnel on Experience with Bombs and Fuzes,* Jacob Rabinow, Memorandum OD-4-19M, NBS, Ordnance Development Division, Jan. 24, 1945. Div. 4-238.515-M4
40. *Eliminating Noise Due to T-50 Gear Trains,* Jacob

Rabinow, Memorandum OD-4-21M, NBS, Ordnance Development Division, Feb. 7, 1945. Div. 4-238.512-M2

41. *Requirements for Doughnut Mechanism,* Jacob Rabinow and J. A. Senn, Memorandum OD-4-39M, NBS, Ordnance Development Division, Mar. 17, 1945. Div. 4-238.515-M5
42. *Arming Pin Considerations for the T-132,* Jacob Rabinow, Memorandum OD-4-44M, NBS, Ordnance Development Division, Apr. 7, 1944. Div. 4-238.513-M3
43. *Compilation of Performance of Various Rotors Tested for Bursting Speed,* Samuel Kolodny, Memorandum OD-4-50M, NBS, Ordnance Development Division, Apr. 28, 1945. Div. 4-232.22-M7
44. *Jolt Test of T-171 Bases,* Louis Schuman, Memorandum OD-4-52M, NBS, Ordnance Development Division, May 7, 1945. Div. 4-238.3-M4
45. *Clock Rotor for the T-132/T-171,* Jacob Rabinow, Memorandum OD-4-67M, NBS, Ordnance Development Division, June 21, 1945. Div. 4-232.22-M8

REPORTS OF CONTRACTORS OF DIVISION 4 OF NDRC

46. *Development of Balancing Equipment for T-171 Turbine Assembly,* M. S. Redden and Allen S. Clarke, OEMsr-1227, Bowen and Company, Electronics Division, May 1945. Div. 4-616-M7
47. *Final Technical Report under Contracts OEMsr-885 and OEMsr-1113,* (Preliminary Draft), OEMsr-885 and OEMsr-1113, Emerson Radio and Phonograph Corporation, May 14, 1945. Div. 4-100-M6

    First Part of Final Report: Interim Reports 31 through 71, OEMsr-2163, Service Project P4-771R, Emerson Radio and Phonograph Corporation.
48. *Summary of Activities in Development and Pilot Manufacturing Run of Radio Fuzes and Accessories and Supplementary Report Covering Development of BRLG (Air Driven Alternator Proximity Fuze),* Final Report, Vernon D. Hauck, OEMsr-258, Friez Instrument Division, Bendix Aviation Corporation, Sept. 27, 1944. Div. 4-100-M4
49. *Generator Powered Proximity Fuze, Type T-2005,* Muriel E. Pottasch, OEMsr-1437, General Instrument Corporation, Aug. 1, 1945. Div. 4-222.125-M2
50. *Generator Powered Radio Proximity Fuze for Mortars, Longitudinal Excitation Type T-132,* Alfred S. Khouri, OEMsr-1117, Globe-Union, Inc., Sept. 30, 1945. Div. 4-222.131-M6
51. *Development and Manufacturing Report on NDRC Gear Reduction Unit for VT Bomb Fuze,* OEMsr-1117, Globe-Union, Inc., Aug. 31, 1945. Div. 4-238.512-M4
52. [Alnico Rotor Generators], *Final Report—Contract OEMsr-1134,* C. W. Clemons, OEMsr-1134, Knapp-Monarch Company, Nov. 20, 1944. Div. 4-232.2-M19
53. *Pilot Line Production of BRLG Equipment* (Final Progress Report), Maurice E. Swift, OEMsr-1196, Philco Radio and Television Corporation, May 31, 1945. Div. 4-211.21-M12
54. [The BRLG Unit], *Final Report of the OSRD Project,* Olga E. Yeaton, OEMsr-866, Philco Radio and Television Corporation, Aug. 18, 1944. Div. 4-211.21-M6
55. *Research and Development Conducted by Philco Corporation on P-4-772 Radio Proximity Fuze for Large Bombs,* Final Report, R. A. Bell, OEMsr-866, Philco Radio and Television Corporation, June 15, 1943. Div. 4-211.1-M4
56. [Development of Special Electronic Devices], *Report to Division 4, NDRC, on Contract OEMsr-1003,* Final Report, Alan M. Glover and Arnold R. Moore, OEMsr-1003, Radio Corporation of America, Oct. 23, 1944. Div. 4-231-M3
57. *Final Technical Report of Raymond Engineering Laboratory, Inc., on Work Done under Contract OEMsr-1378,* OEMsr-1378, Report 238, Raymond Engineering Laboratory, Inc., Oct. 29, 1945. Div. 4-100-M8
58. [Vacuum Tubes, Types NR-2 (2B-24), NR-3 (2C-27) and NR-5 (2E-27)]. *Final Summary Report Regarding Development,* A. Abate, OEMsr-566, Raytheon Manufacturing Company, Oct. 1, 1945. Div. 4-231-M5
59. *Contracts OEMsr-1161, OEMsr-1163 BRLG Proximity Fuzes,* Final Report, OEMsr-1161 and OEMsr-1163, Rudolph Wurlitzer Company, Mar. 15, 1945. Div. 4-211.22-M1
60. *Investigation of Rotative Systems of VT-172 and VT-132 Units,* L. M. K. Boelter, University of California, Department of Engineering, October 1945. Div. 4-232.23-M8
61. *Radio Proximity Fuze, Type MROG,* OEMsr-749, Part I, Report WRL-UF-4, University of Florida, Apr. 2, 1945. Div. 4-211.23-M4
62. *Final Chronological Report on Both the RC Project and the Mortimer Project,* Palmer H. Craig, OEMsr-749, Report WRL-UF-7, University of Florida, May 19, 1945. Div. 4-211.23-M6
63. *Summary Technical Report for Contract OEMsr-769,* OEMsr-769, State University of Iowa, Sept. 29, 1945. Div. 4-100-M7
64. *Final Technical Report on Generator Powered Proximity Fuze for Bombs,* Contract II, Western Electric Company Bell Telephone Laboratory, May 30, 1944.
65. *Photoelectric Fuzes,* Final Report, J. F. Wentz, OEMsr-145 and OEMsr-225, Bell Telephone Laboratories, Mar. 1, 1943. Div. 4-212.2-M4
66. *Proximity Fuze, Rocket, Plane-to-Plane, POD Type,* John R. Boykin, OEMsr-343, Termination Report CFE-761, Westinghouse Electric and Manufacturing Company, Apr. 28, 1945. Div. 4-211.1-M5
67. *Development of a Ground Approach Proximity Fuze for Bomb Nose, BRTG,* T. M. Bloomer,

OEMsr-343 and OEMsr-1106, Termination Report CFE-760, Westinghouse Electric and Manufacturing Company, Apr. 28, 1945. Div. 4-211.21-M11

68. *Proximity Fuze, Bomb, Nose, Ground Approach: Type VT, T-82*, T. M. Bloomer, OEMsr-343 and OEMsr-1106, Termination Report CFE-759, Westinghouse Electric and Manufacturing Company, Apr. 28, 1945. Div. 4-222.113-M2
69. *Proximity Fuze, Hornet*, John R. Boykin, OEMsr-343, Termination Report CFE-762, Westinghouse Electric and Manufacturing Company, Apr. 28, 1945. Div. 4-211.1-M6
70. *Final Technical Report of Work Performed under Contract OEMsr-954*, OEMsr-954, Zell Corporation, Jan. 12, 1945. Div. 4-100-M5
71. *Generator Powered Radio Proximity Fuze for Bombs Transverse Antenna Type*, Final Report, Earl J. Diehl, OEMsr-980 and OEMsr-1133, Service Project OD-27, Zenith Radio Corporation, Mar. 30, 1945. Div. 4-211.21-M9
72. *Generator Powered Radio Proximity Fuze for Mortars: Loop Transverse Antenna Type*, Earl J. Diehl, OEMsr-1477, Service Project OD-27, Zenith Radio Corporation, Oct. 30, 1945. Div. 4-222.132-M1
73. *Development and Manufacturing Report on NDRC Gear Reduction Unit for VT Rocket Fuze*, OEMsr-1117, Globe-Union, Inc., Sept. 14, 1945. Div. 4-238.512-M4
74. *RRLG Proximity Fuzes*, Final Report, F. H. Osborne, OEMsr-1161 and OEMsr-1163, Rudolph Wurlitzer Company, Mar. 15, 1945. Div. 4-211.22-M1
75. *Pilot Production of T-50 Fuzes*, Allen S. Clarke and C. N. Julian, OSRD 5351, OEMsr-1227, Service Projects OD-27, NO-77B, and NO-77R, Report A-335, Bowen and Company, Apr. 12, 1945. Div. 4-222.111-M3
76. *Generator-Powered Proximity Fuzes for Bombs* (Final Technical Report), K. D. Smith and A. L. Stillwell, OEMsr-905, Bell Telephone Laboratories, Mar. 24, 1944. Div. 4-211.21-M5
77. [Battery Requirements for Project K-4], *Final Technical Report on Work Performed on Contract OEMsr-887*, C. B. Pear, Jr., OEMsr-887, Washington Institute of Technology, Feb. 17, 1944. Div. 4-232.1-M8
78. *Generator-Powered Radio Proximity Fuze, Type T-2005*, Muriel E. Pottasch, OEMsr-1437, General Instrument Corporation, Aug. 1, 1945. Div. 4-222.125-M2

Chapter 5

1. *Radio Proximity Fuze for Plane-to-Plane Rocket Application*, Harry M. Diamond, W. S. Hinman, Jr., Robert D. Huntoon, Cledo Brunetti, and C. N. Page, Service Projects OD-27 and OD-26, Report A-144, Armor and Ordnance of NDRC, Feb. 12, 1943. Div. 4-211.1-M3
2. *The Air Burst Proximity Fuze for Bombs, Rockets, and Mortars*, NBS, Ordnance Development Division, National Bureau of Standards, October 1945. Div. 4-211-M3
3. *Computation of Burst Heights of Longitudinally-Excited Bomb Fuzes*, R. P. Schwartz, Report OD-3-281, NBS, Ordnance Development Division, Aug. 7, 1945. Div. 4-241-M8
4. "VT Rocket Fuzes (for Aircraft Rockets)," Ordnance Pamphlet 1470, Apr. 6, 1945.
5. Fuze, Rocket, PD, T-6, TB 9X-93, Dec. 19, 1944.
6. Fuze, Rocket, P.D., T-4 and T-5, TB 9X-94, Dec. 28, 1944.
7. VT Bomb Nose Fuzes, TB 9X-106, Feb. 21, 1945.
8. Test of Fuze, Bomb, Nose T51E1, Army Air Forces (Eglin Field) S.T.P. 1-45-6, Nov. 27, 1945.

SPECIFICATIONS FOR METAL PARTS ASSEMBLIES OF FUZES

9. *Specifications for the Manufacture and Testing of the M-3 (MC-382) Radio Fuze*, Cledo Brunetti, NDRC, Division 4, Sept. 30, 1942. Div. 4-222.128-M1
10. *Technical Specifications for Parts Assemblies for VT Reaction Grid Detection Fuzes, T-30 and T-2004*, Draft 2, NBS, Ordnance Development Division, July 20, 1945.* Div. 4-222.126-M2
11. *Specification for Longitudinally Excited, Generator Powered Radio Proximity Fuze, BRLG-100*, NDRC, Division 4, Feb. 25, 1944. Div. 4-211.21-M4
12. *Fuze, Bomb, Nose, VT, M-168, Parts Assembly*, Tentative Specification, Ordnance Department, U. S. Army, AXS-1691, Apr. 18, 1946.
13. *Specification for Transversely Excited, Generator Powered Radio Proximity Fuze, T-51E1*, NDRC, Division 4, Jan. 5, 1945. Div. 4-211.21-M8
14. *Fuze, Bomb, Nose, VT, T-82E2, Parts Assembly*, Tentative Specification, Ordnance Department, U. S. Army, AXS-1610, July 19, 1945.
15. *Fuze, VT, T-132, Parts Assembly*, Tentative Specification, Ordnance Department, U. S. Army, AXS-1615, July 1, 1945.
16. *Fuze, VT, T-171, Parts Assembly*, Tentative Specification, Ordnance Department, U. S. Army, AXS-1667, July 23, 1945.

Chapter 6

ARMOR AND ORDNANCE REPORTS OF NDRC

1. *Generator-Powered Radio Proximity Fuze for Bombs Transverse Antenna Type*, Earl J. Diehl, OSRD 5111, OEMsr-980 and OEMsr-1133, Service

* No official specification was published for the OD models. The specifications for the OD and RGD models are quite similar except for the RF loading procedure and except for the audio input test circuit.

[redacted]

Projects OD-27 and NO-77B, Final Report A-326, Zenith Radio Corporation, Mar. 30, 1945. Div. 4-211.21-M10

2. *Pilot Production of T-50 Fuzes*, Allen S. Clarke and C. N. Julian, OSRD 5351, OEMsr-1227, Service Projects OD-27, NO-77B, and NO-77R, Report A-335, Bowen and Company, Apr. 12, 1945. Div. 4-222.111-M3

REPORTS OF ORDNANCE DEVELOPMENT DIVISION OF NATIONAL BUREAU OF STANDARDS

3. *Engineering Letters Nos. 1 to 63, Inclusive, Covering the Period May 27, 1944 to August 29, 1945* (No. 58 not microfilmed), NBS, Ordnance Development Division. Div. 4-100-M3
(The aforementioned Engineering Letters cover a variety of items relating to production problems for radio proximity fuzes. They were prepared by the Production Engineering Section of the Ordnance Development Division and transmitted to the various manufacturers engaged in production of fuzes.)

REPORTS OF CONTRACTORS OF DIVISION 4 OF NDRC

4. *Summary of Activities in Development and Pilot Manufacturing Run of Radio Fuzes and Accessories*, Vernon D. Hauck, OEMsr-258, Friez Instrument Division, Bendix Aviation Corporation, Sept. 27, 1944. Div. 4-100-M4
5. *Preliminary Draft of Final Technical Report under Contracts OEMsr-885 and OEMsr-1113*, OEMsr-885 and OEMsr-1113, Emerson Radio and Phonograph Corporation, May 14, 1945. Div. 4-100-M6
6. [Development of the 7-mm Rectifier Disc], *Final Report of the Federal Telephone and Radio Corporation*, T. Smith Taylor, OEMsr-941, Oct. 5, 1943. Div. 4-235-M4
7. *Generator-Powered Radio Proximity Fuze, Type T-2005*, Muriel E. Pottasch, OEMsr-1437, General Instrument Corporation, Aug. 1, 1945. Div. 4-222.125-M2
8. *Generator-Powered Radio Proximity Fuze for Mortars, Longitudinal Excitation Type, T-132*, Alfred S. Khouri, OEMsr-1117, Globe-Union, Inc., Sept. 30, 1945. Div. 4-222.131-M6
9. [Alnico Rotor Generators], *Final Report, Contract OEMsr-1134*, C. W. Clemons, OEMsr-1134, Knapp-Monarch Company, Nov. 20, 1944. Div. 4-232.2-M19
10. [Generators], *Final Report on Contract OEMsr-981*, C. W. Clemons, OEMsr-981, Knapp-Monarch Company, Feb. 17, 1944. Div. 4-232.2-M11
11. Final Progress Report, Contract OEMsr-1196, Maurice E. Swift, OEMsr-1196, Philco Corporation, May 31, 1945. Div. 4-211.21-M12
12. *Final Technical Report on Generator-Powered Proximity Fuzes for Bombs*, K. D. Smith and A. L. Stillwell, OEMsr-905, Contract II, Western Electric Company, Bell Telephone Laboratories, May 30, 1944. Div. 4-211.21-M5
13. *Development of a Ground Approach Proximity Fuze for Bomb, Nose, BRTG*, T. M. Bloomer, OEMsr-343 and OEMsr-1106, Termination Report CFE-760, Westinghouse Electric and Manufacturing Company, Apr. 28, 1945. Div. 4-211.21-M11
14. *Proximity Fuze, Bomb, Nose, Ground Approach, Type VT, T-82*, T. M. Bloomer, OEMsr-343 and OEMsr-1106, Termination Report CFE-757, Westinghouse Electric and Manufacturing Company, Apr. 28, 1945. Div. 4-222.113-M2
15. *Final Technical Report of Work Performed under Contract OEMsr-954*, OEMsr-954, Zell Corporation, Jan. 12, 1945. Div. 4-100-M5
16. *Generator-Powered Radio Proximity Fuze for Mortars, Loop Transverse-Antenna Type*, Earl J. Diehl, OEMsr-1477, Service Project OD-27, Zenith Radio Corporation, Oct. 30, 1945. Div. 4-222.132-M1
17. *Mass Production of T-51 Fuzes by Zenith Radio Corporation* (OEMsr-980 and OEMsr-1133), Oct. 3, 1945.

Chapter 7

ARMOR AND ORDNANCE REPORTS OF NDRC

1. *Analysis of Feedback Amplifiers for MC-382 Fuzes*. Robert D. Huntoon, William L. Kraushaar, and Herbert D. Cook, Progress Report A122, Dec. 7, 1942. Div. 4-238.222-M1
2. *Pilot Production of T-50 Fuzes*, Allen S. Clarke and C. N. Julian, OSRD 5351, OEMsr-1227, Service Projects OD-27, NO-77B and NO-77R, Report A-335, Bowen and Company, Apr. 12, 1945. Div. 4-222.111-M3

NDRC REPORTS AND MEMORANDA

3. *Radiation Properties of BRLG*, Robert D. Huntoon, Service Project OD-27, Memorandum Report 43-R, July 29, 1942. Div. 4-243.11-M1
4. *Description of 1000-G Centrifuge*, Allen S. Clarke, Eng. Memorandum, Nov. 25, 1942. Div. 4-615-M1
5. *Engineering Report on MC-382 Test Equipment*, Preliminary Draft, Nov. 26, 1942. Div. 4-222.128-M3

NDRS SPECIFICATIONS

6. *Specification for Electron Tube NR-2A, a Diode Tube*, Aug. 1, 1944. Div. 4-231.2-M3
7. *Specification for Generator G-1*, NBS, Ordnance Development Division, Nov. 25, 1944. Div. 4-232.2-M20

REPORTS OF ORDNANCE DEVELOPMENT DIVISION OF NATIONAL BUREAU OF STANDARDS

8. *Electronic Frequency Meter,* Charles Ravitsky, Leonard C. Pochop, and J. G. Reid, Jr., Report OD-2-15 (First Series), NBS, Ordnance Development Division, July 26, 1943. Div. 4-613-M1
9. *Rotary Shaker for Pre-Testing BRLG Heads,* Robert D. Huntoon, Report OD-3-7, NBS, Ordnance Development Division, Oct. 22, 1943. Div. 4-614-M1
10. *Critical Grid Voltage of Thyratrons and Hum Voltage Output of BRLG-11,* F. Lamar Cooke, Report OD-3-9, NBS, Ordnance Development Division, Oct. 27, 1943. Div. 4-231.1-M7
11. *Methods of Measuring the Critical Voltage of Thyratrons,* F. Lamar Cooke, Report OD-3-13, NBS, Ordnance Development Division, Oct. 28, 1943. Revised: Nov. 9, 1943. Div. 4-231.1-M8
12. *Generator Performance,* William L. Kraushaar, Report OD-3-17, NBS, Ordnance Development Division, Nov. 1, 1943. Div. 4-232.2-M8
13. *Preliminary Report on Tuning and Loading Device for BRLG,* Paul E. Landis, Report OD-3-37, NBS, Ordnance Development Division, Nov. 29, 1943. Div. 4-233.1-M1
14. *Tuning BRLG,* Robert D. Huntoon, Report OD-3-87, NBS, Ordnance Development Division, Jan. 29, 1944. Div. 4-233.1-M2
15. *BRLG Tuning on Various Vehicles,* Bertrand J. Miller, Report OD-3-106 and Addendum OD-3-106A, Mar. 3 and 20, 1944. Div. 4-231.2-M2
16. Addendum to Report OD-3-106, Bertrand J. Miller and Charles C. Gordon, Report OD-3-106A, NBS, Ordnance Development Division, Mar. 20, 1944. Div. 4-231.2-M2
17. *Microphonic Stability of Oscillator-Diode Type Fuze Circuits,* Robert D. Huntoon, Report OD-3-117, NBS, Ordnance Development Division, Mar. 22, 1944. Div. 4-238.31-M1
18. *Loading Circuit for Final Test Chamber to Be Used at W Frequency and Encasing Cup Specification,* Thomas C. Bagg, Report OD-3-126, NBS, Ordnance Development Division, Apr. 1, 1944. Div. 4-233.1-M3
19. *Testing RGD Units,* Philip Krupen, Report OD-3-131, NBS, Ordnance Development Division, Apr. 22, 1944. Div. 4-238.32-M6
20. *Dummy Antennas,* Robert D. Huntoon, Report OD-3-133, NBS, Ordnance Development Division, Apr. 29, 1944. Div. 4-233-M3
21. *Preliminary Investigation of Characteristics of Test Chamber, with Respect to Relative Position of Unit Therein,* J. L. Pike and Otto E. Spokas, Report OD-3-135, NBS, Ordnance Development Division, Apr. 25, 1944. Div. 4-233.1-M4
22. *Electronic Tachometer,* Herbert D. Cook, Report OD-3-137, NBS, Ordnance Development Division, July 28, 1944. Div. 4-621.1-M1
23. *Triode Microphonics,* Robert D. Huntoon, Report OD-3-153, NBS, Ordnance Development Division, May 20, 1944. Div. 4-231.3-M2
24. *Compensated Resistors for Tuning and Loading Standards,* E. Eisner and Paul T. Hawes, Report OD-3-154, NBS, Ordnance Development Division, May 24, 1944. Div. 4-236-M4
25. *Resonant Loading of BRTG Units by Test Boxes,* Ralph Stair, Glenn L. Scillian, and Leonard C. Pochop, Report OD-3-196, NBS, Ordnance Development Division, Nov. 13, 1944. Div. 4-233.1-M7
26. *The T-132 (Mortar Fuze) Apex Performance Problem,* William L. Kraushaar, Report OD-3-220, NBS, Ordnance Development Division, Mar. 3, 1945. Div. 4-222.131-M2
27. *Test Fixture for Balancing the Single Bearing Nose Assembly,* Jacob Rabinow, Supplement 3 to Report OD-4-48, NBS, Ordnance Development Division, Jan. 13, 1945. Div. 4-616-M6
28. *Compression Test Equipment,* C. Chartock, Report OD-4-50, NBS, Ordnance Development Division, Apr. 27, 1944. Div. 4-623-M1
29. *Torsion Wire Dynamometer,* Louis Schuman, Report OD-4-105, NBS, Ordnance Development Division, May 26, 1945. Div. 4-612-M2
30. *Proposed Design for Dynamic Balancing Machine,* Jacob Rabinow, Report OD-4-108, NBS, Ordnance Development Division, June 6, 1945. Div. 4-616-M8
31. *Report of Shelf Life Test on MC-382 Unit,* Paul J. Martin, Report OD-5-522, NBS, Ordnance Development Division, Oct. 12, 1944. Div. 4-238.222-M5
32. A *Study of the Development of the BRLG-100 Specifications of February 25, 1944,* Report OD-5-617, NBS, Ordnance Development Division, Sept. 1, 1944. Div. 4-211.21-M7
33. *A Study of the Development of the Specification for the Rectifier Bridge Assembly RA-1 of July 5, 1944,* Report OD-5-637, NBS, Ordnance Development Division, Oct. 4, 1944. Div. 4-235-M2
34. *A Study of the Development of the NDRC Specification for Generator G-1 Dated February 25, 1944,* Report OD-5-645, NBS, Ordnance Development Division, Oct. 6, 1944. Div. 4-232.2-M17
35. *A Study of the Development of the Specifications for NR-2A Diode, NR-3/NS-3 Triode, NS-4 Thyratron and NR-5/NS-5 Pentode, Dated August 1, 1944,* Report OD-5-671, NBS, Ordnance Development Division, Oct. 20, 1944. Div. 4-231-M2
36. *Zenith Revised Final Test Position,* Paul E. Landis, Report OD-5-787, NBS, Ordnance Development Division, Apr. 16, 1945. Div. 4-622-M3
37. *Mechanical Properties of Final Test Chamber,* Robert D. Huntoon and T. F. Protz, Report OD-BE-9R, NBS, Ordnance Development Division, July 24, 1944. Div. 4-619-M2
38. *A New Proposal for Shaking Each Unit in Final*

Test, Wendell L. Lees, Report OD-BE-72R, NBS, Ordnance Development Division, Feb. 24, 1945. Div. 4-622-M2

39. *Compensated Tuning Resistors Used in Tuning T-30 Fuzes for Aircraft Rockets (AR and HVAR)*, Paul T. Hawes and Thomas C. Bagg, Report OD-TEG-6R, NBS, Ordnance Development Division, Dec. 14, 1944. Div. 4-236-M7
40. *Test Line for T-132 Unit, Globe-Union and Wurlitzer Model*, Thomas C. Bagg, Engineering Report OD-2-TEG-SR, NBS, Ordnance Development Division, Jan. 30, 1945. Div. 4-222.131-M1
41. *Measurement of Firing Voltage*, Robert D. Huntoon, Project OD-3, NBS, Ordnance Development Division, Aug. 20, 1943. Div. 4-621-M2
42. *Electronic Demagnetizer*, Engineering Letter 40, Jan. 3, 1945.

MEMORANDA OF ORDNANCE DEVELOPMENT DIVISION OF NATIONAL BUREAU OF STANDARDS

43. *Loading Device for BRTG Units*, L. A. Riley and G. J. Tedore, Memorandum OD-5-88M, NBS, Ordnance Development Division, Dec. 26, 1944. Div. 4-233.1-M8
44. *Compensated Versus Uncompensated Resistors for Sensitivity Measurements on RGD Units*, Paul E. Landis, Memorandum OD-5-242M, NBS, Ordnance Development Division, June 25, 1945. Div. 4-328.2-M2
45. *Noise Differences in Final Test Chambers*, Robert D. Huntoon, Memorandum OD-BE-11M, NBS, Ordnance Development Division, June 26, 1944. Div. 4-233.1-M6
46. *Blocking Voltage for Use in Making Audio Test on OD Units*, Herbert D. Cook, Memorandum OD-TEG-35M, NBS, Ordnance Development Division, Feb. 12, 1945. Div. 4-621-M4
47. *Hum Injection Adjustment*, Charles R. Duke, Herbert D. Cook, and Thomas C. Bagg, Memorandum OD-TEG-78M, NBS, Ordnance Development Division, July 28, 1945. Div. 4-621-M5
48. *Tuning and Adjustment of MC-382*. Memorandum to Harry Diamond from W. S. Hinman, Jr., NBS, Ordnance Development Division, Nov. 16, 1942. Div. 4-222.128-M2

REPORTS OF CONTRACTORS OF DIVISION 4 NDRC

49. *Radiation Dummy Load Consideration, MC-382*, R. H. Pintell, Service Project OD-27, Memorandum Report 33R, Emerson Radio and Phonograph Corporation, Mar. 2, 1943. Div. 4-243.12-M1
50. *Development of Balancing Equipment for T-171 Turbine Rotor Assemblies*, M. S. Redden and Allen S. Clarke, OEMsr-1227, Bowen and Company, May 1945. Div. 4-616-M7
51. *Mass Production of T-51 Fuzes by Zenith Radio Corporation*, Earl J. Diehl, OEMsr-1477, Service Project OD-27, Zenith Report of Contract W-28-004-SC-965, Oct. 30, 1945. Div. 4-222.112-M5

U. S. MILITARY REPORTS

52. *Tentative Specifications for Rectifiers*, AXS-1613, Mar. 31, 1945.
53. *Tentative Specifications for Tubes, Vacuum, and Gas Filled*. Ordnance Department, U. S. Army, AXS-1612 (Revision 1), July 25, 1945.
54. *War Department Technical Manual for Quality Control Testing for Ring-Type and Bar-Type VT Nose Metal Parts Assemblies for Bombs and Rockets*.

UNCLASSIFIED TECHNICAL PUBLICATIONS

55. *Measurements of Admittance at UHF*. J. M. Miller and B. Salzberg, RCA Review 3, April 39, p. 486.

DRAWING REFERENCES

Drawing Reference Number	NBS Drawing Index
1	L5515
2	L5516
3	L5524
4	L5526
5	L5529
6	L5530
7	L5531
8	L5532
9	L5533

Chapter 8

ARMOR AND ORDNANCE REPORTS AND MEMORANDA OF NDRC

1. *Radio Reporters for Proximity Fuze Testing*, Allen V. Astin, OSRD 589, Report A-53, May 21, 1942. Div. 4-611-M1
2. *Proving Ground Operations and Facilities for Testing Proximity Fuzes for Bombs and Rockets*, Lauriston S. Taylor, OSRD 719, Memorandum A-44M, July 20, 1942. Div. 4-222.129-M1
3. *Note on a Practical Method for the Field Testing of Radio Proximity Fuzes for Rocket Applications*, Harry M. Diamond and W. S. Hinman, Jr., OSRD 767, Memorandum A-48M, July 30, 1942. Div. 4-222.129-M2
4. *Sampling Formulas for Qualification and Proof Testing of Production Lots*, T. M. White, OSRD 3198, Memorandum A-82M, January 1944. Div. 4-770-M1

NDRC ENGINEERING REPORTS

5. *Proposed Proof Range for M-2 and M-3 Fuzes at Aberdeen*, Harry M. Diamond, Service Project OD-27, Memorandum Report 1-M, Dec. 29, 1942. Div. 4-222.223-M1

6. Chapter 4 ("Exterior Ballistics") of *Rocket Fundamentals*; prepared under the auspices of Section H, Division 3, edited by Bryce L. Crawford, Jr., OSRD 3992, OEMsr-273, Report ABL-SR4, George Washington University, 1944. Div. 4-410-M1
7. Chapter 13 ("Flight Tests of Rockets") of *Rocket Fundamentals*, prepared under the auspices of Section H, Division 3 (OSRD 3992), Report ABL-SR4, 1944. Div. 4-410-M1

REPORTS AND MEMORANDA OF ORDNANCE DEVELOPMENT DIVISION OF NATIONAL BUREAU OF STANDARDS

8. *Frequency of Yaw of Budd 4½" Rockets Fired from a Plane,* Theodore B. Godfrey, Service Project OD-27, Memorandum Report 47-T, NBS, Ordnance Development Division, Feb. 11, 1943. Div. 4-412.2-M1
9. *Three-Dimensional Analysis of 11 Trajectories of PEP-M2 Fuzes Fired from a Plane at Aberdeen, January 23 and 24, 1943,* Theodore B. Godfrey, Service Project OD-27, Memorandum Report 54-T, NBS, Ordnance Development Division, Feb. 11, 1943. Div. 4-222-224-M5
10. *Yaw Reporter Test,* Theodore B. Godfrey and L. C. Miller, Service Project OD-27, Memorandum Report 401-T, NBS, Ordnance Development Division, Aug. 9, 1943. Div. 4-412.2-M2
11. *Salvo Firing in Search of Sympathetic Functioning of MC-380 and MC-382 Fuzes,* F. R. Kotter and T. N. White, Report OD-1-15, NBS, Ordnance Development Division, Sept. 23, 1943. Div. 4-245-M1
12. *Puff Delay, 500-lb Bomb,* Theodore B. Godfrey, Report OD-1-41, NBS, Ordnance Development Division, Nov. 5, 1943. Div. 4-242.13-M1
13. *A Modified Method of Scanning Phonograms,* J. J. Hopfield, Report OD-1-130, NBS, Ordnance Development Division, Feb. 5, 1944. Div. 4-617-M1
14. *Field Test of SW200 0.7-Sec Switches; Photographic Method for Timing Early Functions in High Angle Firing,* H. F. Stimson, R. G. Tobey, and D. W. Scott, Report OD-1-237, NBS, Ordnance Development Division, Apr. 20, 1944. Div. 4-238.511-M5
15. *Static Tests of BRLG Function Indicators,* T. C. Hellmers, L. L. Parker, and L. C. Miller, Report OD-1-272, NBS, Ordnance Development Division, May 3, 1944. Div. 4-626-M1
16. *40 Bowen T-50 E10 on Refrigerated Mk 7,* D. A. Worcester and D. W. Scott, Report OD-1-529, NBS, Ordnance Development Division, Oct. 20, 1944. Div. 4-222.127-M1
17. *Field Test, Rotation of M9A1 with Hand-Crimped Fins,* R. G. Tobey and D. W. Scott, Report OD-1-588, NBS, Ordnance Development Division, Dec. 18, 1944. Div. 4-412.2-M3
18. *Static Tests to Determine the Effect of Different Trap and Motor Combinations on the Functioning of the T-5 Fuze,* H. F. Stimson, John Beek, Jr., E. Allen Cook, and Charles C. Gordon, Report OD-1-589, NBS, Ordnance Development Division, Dec. 15, 1944. Div. 4-222.121-M7
19. *Ballistics of Mk 1 and Mk 7 Motors with T-50 and T-51 Units and Slip Factor Data for Various Vehicles,* D. C. Friedman and G. L. Rabinow, Report OD-1-591, NBS, Ordnance Development Division, Dec. 21, 1944. Div. 4-411.1-M5
20. *Plane Firing of T-30 and Mk 7,* D. W. Scott, Report OD-1-650, NBS, Ordnance Development Division, Feb. 7, 1945. Div. 4-222.124-M1
21. *Effect of Rocket Spin upon the Performance of VT Fuzes T-4, T-5, T-6,* Theodore B. Godfrey, Summary Report OD-1-668, NBS, Ordnance Development Division, Mar. 13, 1945. Div. 4-222.123-M3
22. *Plane Firing, Philco T-2004 on T-87,* D. A. Worcester and D. W. Scott, Report OD-1-744, NBS, Ordnance Development Division, May 10, 1945. Div. 4-222.125-M1
23. *Visibility of Various Mortar Spotting Charges,* R. G. Tobey and G. Rabinow, Report OD-1-829, NBS, Ordnance Development Division, July 11, 1945. Div. 4-626-M2
24. *Afterburning from Rocket Motors and Malfunctioning of VT Fuzes,* H. F. Stimson, Report OD-1-896, NBS, Ordnance Development Division, Oct. 15, 1945. Div. 4-411.11-M6
25. *An Investigation of Mortar-Shell Muzzle Velocities,* H. V. Menapace, M. H. Seibel, and G. L. Rabinow, Report OD-1-909, NBS, Ordnance Development Division, Mar. 14, 1946. Div. 4-515-M1
26. *A Method of Recording Size and Concentration of Raindrops,* Theodore B. Godfrey, R. K. Pickels, and D. A. Worcester, Report OD-1-920, NBS, Ordnance Development Division, May 21, 1946. Div. 4-740-M1
27. *Equivalent Release Conditions for Level Flight Bombing and Dive Bombing,* Irene Freuder, F. L. Celauro, and T. N. White, Technical Memorandum OD-1-TM2, NBS, Ordnance Development Division, Oct. 30, 1945. Div. 4-211.3-M5
28. *Audio Limiter,* W. A. Yates, Technical Memorandum OD-1-TM5, NBS, Ordnance Development Division, Oct. 29, 1945. Div. 4-617-M2
29. *Recording Oscilloscope and 16-mm Eastman Oscilloscope Camera,* N. Newman, Technical Memorandum OD-1-TM8, NBS, Ordnance Development Division, Nov. 2, 1945. Div. 4-617-M3
30. *Intermittent Recording Control,* N. Newman, Technical Memorandum OD-1-TM9, NBS, Ordnance Development Division, Nov. 7, 1945. Div. 4-617-M4
31. *Fifty-Cycle Oscillator,* N. Newman, Technical Memorandum OD-1-TM10, NBS, Ordnance Development Division, Nov. 7, 1945. Div. 4-619-M5
32. *Notes on Loading, Assembly and Storage Pro-*

[redacted]

cedures in Rocket Testing at Blossom Point Proving Ground, R. G. Robey and L. T. Johnson, Technical Memorandum OD-1-TM19, NBS, Ordnance Development Division, Sept. 25, 1945. Div. 4-412.4-M7

33. *Notes on Mock-Plane Target, Rocket Launchers and Firing Procedures at Blossom Point*, A. P. Sutten, Technical Memorandum OD-1-TM20, NBS, Ordnance Development Division, Sept. 25, 1945. Div. 4-412.4-M8
34. *Notes on Drainage, Firing Tower Construction, Fire Prevention and Observational Procedures at Blossom Point Proving Ground*, R. G. Tobey, Technical Memorandum OD-1-TM21, NBS, Ordnance Development Division Sept. 25, 1945. Div. 4-412.4-M9
35. *Navy Rocket Trajectory Analysis*, A. L. Leiner, Memorandum OD-2-203, NBS, Ordnance Development Division, May 5, 1945. Div. 4-412.1-M8
36. *Standard Statistical Methods for Testing the Difference between Mean Values*, B. M. Bennett, Memorandum OD-2-205M, NBS, Ordnance Development Division, May 7, 1945. Div. 4-770-M3
37. *Early Functions of MC-382 Radio-operated Plane-to-Plane Rocket Fuze*, Bertrand J. Miller and Robert D. Huntoon, Progress Report OD-3-AB2, NBS, Ordnance Development Division, June 8, 1943. Div. 4-222.128-M12
38. *Tests BJM-5 and BJM-6*, Charles Ravitsky, Progress Report OD-7-206R, NBS, Ordnance Development Division, May 14, 1945. Div. 4-222.124-M3
39. *Sequential Analysis of Statistical Data: Applications*, T. N. White and H. C. Doob, Report OD-OAG-46, NBS, Ordnance Development Division, Sept. 27, 1944. Div. 4-770-M2
40. [Cenco Rocket] *Motor*, NBS Drawing 440 R, NBS, Ordnance Development Division, May 20, 1942. Div. 4-411.1-M2

REPORTS OF CONTRACTORS OF DIVISION 4 OF NDRC

41. Chapter VI of *Summary Technical Report*, Contract OEMsr-769, submitted by James A. Jacobs, State University of Iowa, Sept. 29, 1945. Div. 4-100-M7
42. Chapter VII of *Summary Technical Report*, Contract OEMsr-769, submitted by James A. Jacobs, State University of Iowa, Sept. 29, 1945. Div. 4-100-M7
43. *Clinton Field Station Report 60*, State University of Iowa.
44. *Mortar Fuze Recovery*, W. E. Nickell OEMsr-769, Report MB-3-1-45, State University of Iowa, Mar. 31, 1945. Div. 4-619-M4
45. *The Calculation of Trajectories*, L. E. Ward, OEMsr-769, Technical Report T3-8-1-45, State University of Iowa, Aug. 29, 1945. Div. 4-512-M3
46. *The Effects on Trajectories of Small Changes in Initial Conditions with Application to Wind Corrections*, L. E. Ward, OEMsr-769, Technical Report T3-9-1-45, State University of Iowa, Sept. 12, 1945. Div. 4-512-M4

UNITED STATES MILITARY PUBLICATIONS

47. *War Department Manual TM11-2410.*
48. *Handbook of Instructions and Parts Catalog AN10-25-50.*

Chapter 9

ARMOR AND ORDNANCE REPORTS OF NDRC

1. *Radio Proximity Fuze for Plane-to-Plane Rocket Application*, Harry M. Diamond, W. S. Hinman, Jr., Robert D. Huntoon, Cledo Brunetti, and Chester H. Page, Service Projects OD-27 and OD-26, Report A-144, Feb. 12, 1943. Div. 4-211.1-M3
2. *Sampling Formulas for Qualifications and Proof Testing of Production Lots*, T. N. White, OSRD 3198, Memorandum A-82M, January 1944. Div. 4-770-M1
3. Reports Pertinent to Early and Middle Functioning of MC-382 Fuze, as follows:
   - 3a. *A Study of the Relation between Afterburning and Thyratron Voltage*, R. Vorkink, Service Project OD-27, Memorandum Report 158-T, Apr. 14, 1943. Div. 4-238.212-M3
   - 3b. *Tests with Eccentric and with Non-Eccentric Powder, High-Angle Firing*, R. Vorkink, Service Project OD-27, Memorandum Report 338-T, June 1943. Div. 4-222.128-M11
   - 3c. *Test for Ride Through with Various Powders and Firing Angles*, R. Vorkink, Service Project OD-27, Memorandum Report 383-T, Aug. 5, 1943. Div. 4-222.128-M14
   - 3d. *Fuze T6, Range, Dispersion, and Water Approach Function*, D. C. Friedman, Service Project OD-27, Memorandum Report 388-T, July 28, 1943. Div. 4-222.128-M13
   - 3e. *Test of Effect of Velocity on Early Functioning*, R. Vorkink, Service Project OD-27, Memorandum Report 405-T, Aug. 12, 1943. Div. 4-222.128-M15
4. *A Comparison of Several Makes of MC-382 Fuze with Respect to Early, Target and Late Functions and Duds*, T. N. White, Memorandum Report 220-T, May 13, 1943, and Supplement to *A Comparison of Several Makes of MC-382 Fuze with Respect to Early, Target and Late Functions and Duds*, T. N. White, Service Project OD-27, Memorandum Report 282-T, June 10, 1943. Div. 4-222.128-M10

REPORTS OF ORDNANCE DEVELOPMENT DIVISION OF NATIONAL BUREAU OF STANDARDS

5. Reports pertinent to early and middle functioning of the MC-382, as follows:

[redacted]

5a. *Relation between Early Function and Afterburning,* T. N. White, Report OD-1-AB1, NBS, Ordnance Development Division, Mar. 17, 1943. Div. 4-222.129-M3

5b. *Effect of Powder Lot on Afterburning and Slivers,* L. C. Miller, Report OD-1-AB2, NBS, Ordnance Development Division, Mar. 18, 1943. Div. 4-411.11-M2

5c. *The Effect of Powder Load on Afterburning and Slivers,* L. C. Miller, Report OD-1-AB3, NBS, Ordnance Development Division, Mar. 20, 1943. Div. 4-222.128-M4

5d. *Effect of Fin Structure on Early Functioning,* L. C. Miller, Report OD-1-AB4, NBS, Ordnance Development Division, Mar. 23, 1943. Div. 4-222.128-M5

5e. *Early Function Tests (1) Fuzes with Reduced Sensitivity, (2) Motors with Metal Sweeps,* L. C. Miller, Report OD-1-AB5, NBS, Ordnance Development Division, Mar. 23, 1943. Div. 4-222.128-M6

5f. *Early Functions with MC-382 Fuze, Further Testing with Sweeps and with Powders,* T. N. White, Report OD-1-AB6, NBS, Ordnance Development Division, Mar. 27, 1943. Div. 4-222.128-M7

5g. *Experiments on Early Functioning with Revere Motors (1) Soldering of Fin Retaining Rings, (2) Test of Powder Lot 9978, (3) Soldering of Fins in Open Position,* L. C. Miller, Report OD-1-AB7, NBS, Ordnance Development Division, Mar. 31, 1943. Div. 4-411.2-M2

5h. *Static Tests on Afterburning (1) Use of Metal Sweeps, (2) Use of JP-265 Powder,* L. C. Miller, Preliminary Report OD-1-AB8, NBS, Ordnance Development Division, Mar. 29, 1943. Div. 4-411.11-M3

5i. *Progress Report on Afterburning,* H. F. Stimson, Progress Report OD-1-AB9, NBS, Ordnance Development Division, Apr. 9, 1943. Div. 4-411.11-M4

5j. *High-Angle Firing with MC-382 Fuzes [Part] A. Early Function Tests (1) Detuning of Units (2) Use of Sweeps and Plugs; [Part] B. Tests of Mechanical SD Switches,* L. C. Miller, Final Report OD-1-AB11, NBS, Ordnance Development Division, Apr. 17, 1943. Div. 4-222.128-M8

5k. *Incidence of Early Functions with POD Type Fuzes and MC-382 Fuzes: Comparisons Based on Target Function and High-Angle Firing Tests,* T. N. White, Report OD-1-AB12, NBS, Ordnance Development Division, May 1, 1943. Div. 4-222.129-M4

5l. *Tests of Sweeps and Plugs,* R. Vorkink, Report OD-1-AB13, NBS, Ordnance Development Division, May 7, 1943. Div. 4-222.128-M9

5m. *High-Angle Night Firing with Powders A-20, A-21, and A-22: Afterburning, Burning Distances,* H. F. Stimson, Report OD-1-AB14, NBS, Ordnance Development Division, May 13, 1943. Div. 4-411.11-M5

5n. *RC Delay Added to SW-200 Arming Switches, Effect on Early Functioning of MC-382 Fuzes,* T. N. White, Report OD-1-AB15, NBS, Ordnance Development Division, Sept. 14, 1943. Div. 4-222.128-18

5o. *Tests for Early Functioning with Different Powder Weights,* R. Vorkink, Report OD-1-AB16, NBS, Ordnance Development Division, Aug. 26, 1943. Div. 4-222.128-M16

5p. *Test for Mal-Functions of MC-382 with Special Fin Motors (No Locking Burr),* R. Vorkink, Report OD-1-1, NBS, Ordnance Development Division, Sept. 2, 1943. Div. 4-222.128-M17

5q. *Tests on Early Functioning of MC-382 Fuzes [Part] A. Use of Purge Pellets; [Part] B. Increased Surface Area of Propellant,* L. C. Miller, Report OD-1-5, NBS, Ordnance Development Division, Sept. 14, 1943. Div. 4-222.128-M19

5r. *Effect of Propellant on Early Functioning [Part] A. Amount of Regular Propellant; [Part] B. Special Propellant; [Part] C. Purge Pellets,* T. N. White, Report OD-1-8, NBS, Ordnance Development Division, Sept. 21, 1943. Div. 4-222.128-M21

5s. *Test of Propellant Charge on Early Functioning,* R. Vorkink, Report OD-1-13, NBS, Ordnance Development Division, Sept. 20, 1943. Div. 4-222.128-M20

5t. *Test of Effect of Purge Pellets on Early Functioning,* R. Vorkink, Report OD-1-17, NBS, Ordnance Development Division, Sept. 30, 1943. Div. 4-222.128-M22

5u. *Early Functioning of MC-382 Fuzes, Purge Pellet Field Test 5,* L. C. Miller, Report OD-1-22, NBS, Ordnance Development Division, Oct. 6, 1943. Div. 4-222.128-M23

5v. *Early Functioning of MC-382 Fuzes, Purge Pellet Field Tests 6 and 7,* L. C. Miller, Report OD-1-24, NBS, Ordnance Development Division, Oct. 13, 1943. Div. 4-222.128-M24

5w. *MC-382 Fuze Performance as Affected by Motors with Non-Locking Type Fins,* T. N. White, L. C. Miller, and R. Vorkink, Report OD-1-27, NBS, Ordnance Development Division, Oct. 15, 1943. Div. 4-222.128-M25

5x. *MC-382 Fuze Performance as Affected by Motors with Fins Welded into the Opened Position,* D. C. Friedman, Report OD-1-40, NBS, Ordnance Development Division, Nov. 4, 1943. Div. 4-222.128-M26

5y. *Early Functioning of MC-382 Fuze, Purge Pellet Field Test 8 (Also Tests with POD*

Type Fuzes and with Pressure-Control Valves), T. N. White and R. Vorkink, Report OD-1-42, NBS, Ordnance Development Division, Nov. 19, 1943. Div. 4-222.128-M27

5z. *Purge Pellet Test 9 Including Test of (1) Combination of Motors and Propellants, (2) A New Salted Powder, (3) Pressure-Control Valves*, R. Vorkink, Report OD-1-59, NBS, Ordnance Deevlopment Division, Nov. 23, 1943. Div. 4-222.128-M28

5aa. *High-Angle Test of MC-382 Units to Determine Propellant-Motor Combination for Acceptance Testing*, D. C. Friedman, Report OD-1-119, NBS, Ordnance Development Division, Jan. 26, 1944. Div. 4-222.128-M29

5bb. *Field Test of Eight Lots of Pellets*, R. Vorkink, Report OD-1-125, NBS, Ordnance Development Division, Jan. 29, 1944. Div. 4-222.128-M30

5cc. *Test of T5 and T6 on Motors with Spring-Operated Fins*, D. C. Friedman, Report OD-1-171, NBS, Ordnance Development Division, Feb. 26, 1944. Div. 4-222.123-M1

5dd. *Test to Compare Performance of Type S (BRLG-6 Amplifier) and Standard MC-382 Units*, R. Vorkink, Report OD-1-189, NBS, Ordnance Development Division, Mar. 8, 1944. Div. 4-222.128-M31

5ee. *Comparison of Performance of Type S and Standard MC-382 on Motors with Scallop-Type Traps*, R. Vorkink, Report OD-1-197, NBS, Ordnance Development Division, Mar. 15, 1944. Div. 4-222.128-M32

5ff. *Early Functioning of T5 Units, Tests of Powder Lots, Motor Lots, Igniters, Traps*, D. W. Scott and T. N. White, Report OD-1-227, revised Sept. 22, 1944. Div. 4-222.121-M6

5gg. *Further Testing with Pellets and Salted Powders*, D. W. Scott, Report OD-1-241, NBS, Ordnance Development Division, Apr. 18, 1944. Div. 4-222.128-M33

5hh. *Effect of Trap Structure on Early Functioning of T5 Fuzes*, D. W. Scott, Report OD-1-253, NBS, Ordnance Development Division, Apr. 22, 1944. Div. 4-222.128-M34

5ii. *Effect of Fins on Mal-Functioning of T6 Fuze*, D. W. Scott, Report OD-1-259, NBS, Ordnance Development Division, Apr. 25, 1944. Div. 4-222.122-M1

5jj. *Effect of Salted Powder on Performance of MC-382 Fuzes*, D. W. Scott, Report OD-1-274, NBS, Ordnance Development Division, May 3, 1944. Div. 4-222.128-M35

5kk. *Test of T6 Fuzes on Rigid-Fin Projectiles*, D. W. Scott, Report OD-1-280, NBS, Ordnance Development Division, May 15, 1944. Div. 4-222.122-M2

5ll. *Effect of Notched-Powder Loads on MC-382 Functioning*, D. W. Scott, Report OD-1-287, NBS, Ordnance Development Division, May 27, 1944. Div. 4-222.128-M36

5mm. *Field Test of T5 on Projectiles with Bubble-Wire Traps*, D. W. Scott, Report OD-1-368, NBS, Ordnance Development Division, June 19, 1944. Div. 4-222.121-M1

5nn. *Test of T5 and T6 on Projectiles with Loose Joints*, D. W. Scott, Report OD-1-395, NBS, Ordnance Development Division, July 8, 1944. Div. 4-222.123-M2

5oo. *Test of T5 on Projectiles with Crimped and Brazed Fins*, D. W. Scott, Report OD-1-403, NBS, Ordnance Development Division, July 17, 1944. Div. 4-222.121-M3

5pp. *Test of T5 on Projectiles with Salted Powder and Bubble-Wire Traps*, D. W. Scott, Report OD-1-397, NBS, Ordnance Development Division, July 10, 1944. Div. 4-222.121-M2

5qq. *Performance of T6 with 10A Amplifiers on M9, M9A1 and M9A2 Motors*, D. W. Scott, Report OD-1-404, NBS, Ordnance Development Division, July 21, 1944. Div. 4-222.128-M37

5rr. *Effect of Bayonet and Bag Igniters on Functioning of T5 Fuze*, D. W. Scott, Report OD-1-408, NBS, Ordnance Development Division, July 19, 1944. Div. 4-222.121-M4

5ss. *High-Angle Test of T5 with 10A Amplifier (Some Shaker-Tested) on Motors with Hand-Crimped Fins, Straightened and Unstraightened*, D. W. Scott, Report OD-1-423, NBS, Ordnance Development Division, July 27, 1944. Div. 4-222.128-M38

5tt. *Performance of Shaker-Tested T5 with 10A Amplifier*, D. W. Scott, Report OD-1-477, NBS, Ordnance Development Division, Aug. 24, 1944. Div. 4-222.128-M39

5uu. *T5 on M9A1 with Clamp-On Fixed Fins*, D. W. Scott, Report OD-1-486, NBS, Ordnance Development Division, Sept. 5, 1944. Div. 4-222.121-M5

5vv. *Flight Test of T5 Fuzes on T22 Rockets with EJA Propellant*, D. W. Scott, Report OD-1-614, NBS, Ordnance Development Division, Jan. 4, 1945. Div. 4-222.121-M8

5xx. *Effect of Trap Length on Incidence of Early Functions in the T5*, D. W. Scott, Report OD-1-691, NBS, Ordnance Development Division, Mar. 29, 1945. Div. 4-222.121-M12

6. *Salvo Firing in Search of Sympathetic Functioning of the MC-382*, T. N. White, Report OD-1-15, NBS, Ordnance Development Division, Sept. 25, 1943. Div. 4-245-M1

7. *Rotation of M9A1 with Hand-Crimped Fins*, D. W. Scott, Report OD-1-588, NBS, Ordnance Development Division, Dec. 18, 1944. Div. 4-412.2-M3

8. *Effect of Rocket Spin upon the Performance of VT Fuzes T4, T5, T6*, Theodore B. Godfrey, Re-

[redacted]

port OD-1-668, NBS, Ordnance Development Division, Mar. 13, 1945. Div. 4-222.123-M3

9. *Effect of Rain upon the Performance of VT Fuzes, T5 and T6,* Theodore B. Godfrey, Report OD-1-669, NBS, Ordnance Development Division, Mar. 13, 1945. Div. 4-222.123-M4
10. *Effect of Rocket Spin on T5 Performance,* D. W. Scott, Report OD-1-677, NBS, Ordnance Development Division, Mar. 21, 1945. Div. 4-222.121-M9
11. *Effect of Rocket Spin on T5 Arming Distance,* D. W. Scott, Report OD-1-678, NBS, Ordnance Development Division, Mar. 21, 1945. Div. 4-222.121-M10
12. *Arming Time of T5 on T22 Fired Spiral Launcher,* D. W. Scott, Report OD-1-689, NBS, Ordnance Development Division, Mar. 28, 1945. Div. 4-222.121-M11
13. *Effect of Rotation Upon the Operation of the SW-230 Switch,* Charles C. Gordon, Report OD-1-729, NBS, Ordnance Development Division, Apr. 30, 1945. Div. 4-238.511-M6
14. *Ballistic Test, M43C Shell with Various Fuzes,* G. Rabinow, Report OD-1-737, NBS, Ordnance Development Division, May 8, 1945. Div. 4-514-M3
15. *Field Test of 140 Philco T91 and 120 Emerson T92 —Various Release Conditions, Army Ordnance Test,* R. Vorkink, Report OD-1-825, NBS, Ordnance Development Division, July 9, 1945. Div. 4-222.114-M2
16. *High-Angle and Target Test of T5 and T50 on T22 Rockets Modified for Helical Launcher,* B. M. Bennett, Report OD-1-895, NBS, Ordnance Development Division, Oct. 8, 1945. Div. 4-222.129-M5
17. *Afterburning from Rocket Motors and Malfunctioning of VT Fuzes* (Summary Report), H. F. Stimson, Report OD-1-896, Oct. 15, 1945. Div. 4-411.11-M6
18. *Summary of Experimental Field Test Results of Bomb Fuzes by Test Request Number,* Ordnance Analytical Group, Report OD-2-224, NBS, Ordnance Development Division. Div. 4-222.11-M1
19. *Summary of Pre-Production Mortar Fuze Field Test Results,* Ordnance Analytical Group, Report OD-2-229, NBS, Ordnance Development Division, June 18 and Sept. 27, 1945. Div. 4-222.131-M4
20. *Mortar Fuze Arming Time Tests,* Ordnance Analytical Group, Report OD-2-230, NBS, Ordnance Development Division, June 23 and July 14, 1945. Div. 4-222.131-M5
21. *Summary of Rocket Fuze Plane Firing (Air-to-Earth) Tests,* Ordnance Analytical Group, Report OD-2-269, NBS, Ordnance Development Division, Aug. 24, 1945. Div. 4-222.126-M3
22. *Arming of VT Fuzes: Analysis and Measurement of Spread in Air-Travel-to-Arming,* A. L. Leiner, Report OD-2-275, NBS, Ordnance Development Division, Mar. 14, 1946. Div. 4-244.1-M3
23. *Arming Considerations in T6,* Bertrand J. Miller and Philip R. Karr, Report OD-3-74, NBS, Ordnance Development Division, Jan. 22, 1944. Div. 4-238.515-M1
24. *Minimum Useful Range for T6,* Robert D. Huntoon, Report OD-3-98, NBS, Ordnance Development Division, Feb. 9, 1944. Div. 4-238.515-M2
25. *Computation of Burst Heights of Longitudinally-Excited Bomb Fuzes.* R. B. Schwartz, Report OD-3-281, NBS, Ordnance Development Division, Aug. 7, 1945. Div. 4-241-M8
26. *Summary of Rocket Fuze Experimental Field Test Results,* Analytical Group, Paul F. Bartunek and C. F. Smolen, Report OD-7-97M, NBS, Ordnance Development Division, Apr. 2, 1945. Div. 4-222.12-M1
27. *Summary of Recent Target Tests at Blossom Point,* Alex Orden and C. F. Smolen, Report OD-7-98, NBS, Ordnance Development Division, Apr. 9, 1945. Div. 4-222.12-M2
28. *Analysis of Variations in the Spread of Air-Travel-to-Arming,* B. M. Bennett, Report OD-7-103, NBS, Ordnance Development Division, Apr. 11, 1945. Div. 4-244.1-M2
29. *Summary of Tests of T30 and T2004 Rocket Fuzes during the Period November 30, 1944 to March 31, 1945,* Paul F. Bartunek, Report OD-7-108, NBS, Ordnance Development Division, Apr. 30, 1945. Div. 4-222.126-M1
30. *Mortar Fuze Field Test Results, Experimental Tests by Test Request,* Analytical Group, Paul F. Bartunek and C. F. Smolen, Report OD-7-112, NBS, Ordnance Development Division, Apr. 23, 1945. Div. 4-222.133-M1
31. *Tests BJM-5 and BJM-6,* Charles Ravitsky, Progress Report OD-7-206R, NBS, Ordnance Development Division, May 14, 1945. Div. 4-222.124-M3

MEMORANDA OF ORDNANCE DEVELOPMENT DIVISION, NBS

32. *Mid-Functioning, Section 1 Memo to Harry M. Diamond from H. F. Stimson,* NBS, Ordnance Development Division, June 5, 1944. Div. 4-222.122-M3
33. *Prediction of T51 Burst Height,* D. A. Worcester, Technical Memorandum OD-1-TM-11, NBS, Ordnance Development Division, Nov. 8, 1945. Div. 4-241-M9
34. *Relation between the Spread in Burst Heights and the Mean Burst Height of VT Bomb Fuzes,* R. C. Stillinger, Technical Memorandum OD-1-TM-13, NBS, Ordnance Development Division, Dec. 13, 1945. Div. 4-241-M10
35. *Empirical Burst Height Distribution Formulae for VT Bomb Fuze,* R. C. Stillinger and Irene Hess, Technical Memorandum OD-1-TM-23, NBS, Ordnance Development Division, Sept. 17, 1946. Div. 4-241-M11

36. *A Comparison of Observed and Predicted Burst Heights of Ring-Type VT Bomb Fuzes*, W. J. Cronin and T. N. White, Technical Memorandum OD-1-24M, NBS, Ordnance Development Division, Sept. 19, 1946. Div. 4-241-M12
37. *Analysis of T30 and T2004 FOMA Tests*, F. L. Celauro, Memorandum OD-2-272M, NBS, Ordnance Development Division, Sept. 19, 1946. Div. 4-126-M4

REPORTS OF CONTRACTORS OF DIVISION 3 (SECTION L) OF NDRC

38. *Trajectories of Aircraft Rockets 3.5" and 5.0"*, OSRD 2225, OEMsr-418, Service Projects OD-162, OD-164, and NC-170, Division 3 Report CIT UBC 27, California Institute of Technology, Sept. 25, 1944. Div. 4-412.1-M2

REPORTS OF CONTRACTORS OF DIVISION 4, NDRC

39. *Final Report: Summary Technical Paper*, State University of Iowa Staff, Contract OEMsr-769, Sept. 29, 1945. Div. 4-100-M7

REPORTS OF APPLIED MATHEMATICS PANEL

40. *Probability that a 4.5" Rocket Fired from Astern Will Destroy a Twin-Engine Bomber (Ju-88) as a Function of the Point of Burst*, Statistical Research Group, Columbia University, AMP Report 21.1R, July 1944, and *Optimum Burst Surface for 4.5" Airborne Rocket Fired from Astern at Twin-Engine Bomber (Ju-88)*, AMP Report 21.2R, Statistical Research Group, Columbia University, July 1944. Div. 4-412.3-M1, Div. 4-412.3-M2
41. *Effectiveness of a 4.5" Airborne Rocket with T5 Fuze when Fired at Twin-Engine Bomber from Astern*, AMP Report 21.3R, Statistical Research Group, Columbia University, July 1944. Div. 4-412.3-M3

U. S. MILITARY PUBLICATIONS

Navy

42. *Final Report on Air-to-Air Firing of Mk-171 Mod 0 Fuzes in 3.5" and 5.0" AR*, NOTS Project 104 AFS, Serial 52, Aug. 5, 1945.
43. *Final Report on Air-to-Ground Firing of Mk-172 Mod 0 Fuzes with 5.0" AR*, NOTS Project 106 AF, May 3, 1945.

Army

44. *Proof Testing—A Brief Statistical Description of Final Acceptance Sampling Formulas and Proving Ground Test Performance*, W. Steele and E. J. Fister, Camp Evans Signal Laboratory, Technical Memo SA-Q1, Feb. 3, 1945.
45. *Second Interim Report on Test of Fuzes, Bomb, T50, Army Air Forces Board* (Eglin Field, Florida), Project F4012 (Test S.T. 1-44-12), Mar. 29, 1945.
46. *Final Report on Test of Napalm-Gasoline Filled M-10 Tanks with T50 and T51 Fuzes for Use as an Incendiary Bomb*, Army Air Forces Board (Eglin Field, Florida), Project F4222 (Test S.T. 1-44-91), Apr. 20, 1945.
47. *Final Report on Comparison of the Effectiveness of Bombs against Enemy Installations*, Army Air Forces Board (Eglin Field, Florida), Project F4475 (Test S.T. 1-45-19), May 14, 1945.
48. *Supplemental Test on Aircraft Rockets for Anti-Personnel Effect*, Army Air Forces Board (Eglin Field, Florida), Project 4514 C471.94 (Test S.T. 2-45-16) Sept 4, 1945.
49. *Test of Fuze, Bomb, Nose T51E1*, Army Air Forces (Eglin Field, Florida), S.T.P 1-45-6, Nov. 27, 1945.
50. *First Partial Report of Test of 4.5-Inch Rockets and Rocket Launcher, T-18E2 and T-20*, Field Artillery Board, Fort Bragg, N. C., Jan. 17, 1944.
51. *Procedure for Conducting Field Engineering Acceptance Tests of Metal Parts Assemblies of VT Bomb Fuzes*, L. L. Parker, Apr. 3, 1945.
52. *Tentative Specification, Ordnance Department, AXS-1603*, May 9, 1945.
53. *Procedure for Conducting Field Engineering Acceptance Tests of Metal Parts Assemblies of VT Fuze T2004*, Army Ordnance Specifications, May 11, 1945.
54. *Procedure for Conducting Field Engineering Acceptance Tests of Metal Parts Assemblies of VT Fuze T2004*, Army Ordnance Specifications, Aug. 3, 1945.
55. *Army Ordnance Specifications AXS-1603* (Revision 1), Aug. 13, 1945.

SUBDIVISION OF REFERENCES

56. In reference 26 the following test numbers: TBG-93, -111, -115, -122A, -122B, -127, -130C, RQ-1C.
57. In reference 26 the following test numbers: TBG-114, -120, -123, -124, -125, -128, RQ1A, RX2.
58. In reference 26 the following test numbers: TBG-80, -90, -105, -131, -132, RX1A.
59. In reference 26 the following test numbers: TBG-91, -94, -101, -105.
60. In reference 26 the following test numbers: TBG-82, -86, -87, -88, -93, -103.
61. In reference 26 the following test numbers: TBG-107, -108, -109A, -110, -113, -116, -117, -121, -126, -130A.
62. In reference 26 the following test number: TBG-130B.
63. In reference 26 the following test number: TBG-109B.
64. In reference 26 the following test number: TBG-113.
    64a. In reference 26 the following test number: TBG-85B.

64b. In reference 26 the following test numbers: TBG-112, O118, -119.

65. In reference 18 the following test numbers: CB-257, -270, -271, -272, -285, -301, -323, -324, -341, -358, -389, -396, -414, -419, -420, -423, -431, -434, -435, -445, -446, -448, -451, -452, -453, -454, -458, -460, -462, -472, -474, -478, -483, -499, -500, -508, -509, -518, -523, -527, SC-5, -9, -10, -12, -13, -14, -15, -16, -17, -19, -20, PX-10, BX-4, -5.

66. In reference 18 the following test numbers: CB-468, -491, -493, -501, -504, -506, -511, -515, -517, -526, BX-1.

67. In reference 18 the following test number: CB-506.

68. In reference 18 the following test numbers: CB-468, -475, -491, -501, -515, BX-1.

69. In reference 18 the following test numbers: CB-493, -504, -511, -517, BX-1.

70. In reference 18 the following test numbers: CB-410, -416, -476, -502, PX-5, SC-7.

71. In reference 18 the following test numbers: CB-344, -354, -376, -386, -489, -522, CEX-5, -7, BX-6.

72. In reference 18 the following test numbers: CB-482, -485, -486, -487, -495.

73. In reference 18 the following test numbers: CB-266, -349, -359, LSP-1, Ordnance Test (Aberdeen).

74. In reference 18 the following test numbers: CB-487, -495, -514, -516, -522, BX-6.

75. In reference 18 the following test numbers: CB-485, -486, -489, -495.

76. In reference 18 the following test numbers: CB-475, -476, -489, -502.

77. In reference 18 the following test numbers: CB-283, -284, -286, -289, -290, -291, -292, -294, -295, -297, -299, -300, -304, -305, -307, -309, -310, -311, -313, -314, -326, -327, -328, CHP-20, -21.

78. In reference 18 the following test numbers: CB-475, -476, -482, -485, -486, -487, -495, -502, -515.

79. In reference 18 the following test numbers: CB-344, -354, -386, -410, -416, -468, -482, -485, -486, -487, -489, -491, -493, -495, -501, -504, -506, -511, -515, -517, -522, -526, PX-5, SC-6, -7, CEX-5, -7, BX-1, -6.

80. In reference 18 the following test numbers: CB-266, -349, -359, Dahlgren test of T91, Ordnance Test (Aberdeen).

81. In reference 18 the following test numbers: CB-357, -360, -365, -369, -370, -371, -372, -373, -377, -378, -379, -387, -388, -393, -402, -404, -411, -412, -413, -417, -418, -421, -429, -430, -447, -450, -451, -455, -458, -459, -461, -463, -465, -469, -473, -477, -480, -488, -492, -497, -498, -500, -503, -513, -518, -521, BX-1, -3, -7, -8, -11, -13, -15, -17, -18.

82. In reference 18 the following test numbers: CB--458, -459, -469, -477, -479, -480, -488, -492, -498, -513, -518, -521, BX-3, -8, -11, -15, -18.

83. In reference 18 the following test numbers: CB-369, -370, -371, -372, -425, -429, -447, -450, -451, -457, -461, -463, -464, -465, -481, -500, -503, -510, BX-1, -7, -16, -17.

84. In reference 18 the following test numbers: CB-497, -500, -510.

85. In reference 18 the following test numbers: CB-357, -360, -365, -370, -371, -372, -373, -381, -387, -388, -393, -398, -399, -401, -404, -411, -413, -417, -429, -447, -450, -451, -455, -458, -461, -465, -469, -473, -477, -480, -481, -488, -492, -497, -498, -500, -503, -513, -518, -529, BX-1, -3, -7, -8, -11, -15, -17, -18.

86. In reference 18 the following test numbers: CB-473, -480, -492, -496, -497, -498, -500, -507, -513, -519, -525, BX-1, -3, -7, -8, -14, -15, -18.

MISCELLANEOUS REFERENCES PERTAINING TO EFFECTIVENESS OF PROXIMITY FUZES

87. "Trials with AN-M.64 Bombs, Nose Initiated (T-50) against Close Support Targets," Ordnance Board Proceedings No. Q2881, E. S. Pearson and B. L. Welch, Dec. 13, 1944.

88. "Bombs, Aircraft, and Fuzes, Bomb, Aircraft: (1) Report on test conducted in U. S. A.; (2) Theoretical calculations on optimum height of burst of aircraft bombs fitted with V.T. fuzes." Ordnance Board Proceedings No. Q3860; notes, E. S. Pearson, Oct. 29, 1945.

89. *Airburst for Blast Bombs*, E. B. Wilson, Jr., NDRC Report A-322, April 1945.

90. *Effect of Height of Detonation of Bombs on the Blast Pressures and Impulses of Surrounding Buildings, in Richmond Park 1/7 Square Model Town Tests*, Road Research Laboratory, Department of Scientific and Industrial Research, Ministry of Supply, Note No. MOS/434/RJ.EK, March 1945.

91. "Air Burst Bombs," Memorandum from A. H. Taub (Division 2, NDRC) to Col. P. Schwartz (Director of Armament, USSTAF), Dec. 21, 1944.

92. "Air Burst Bombs—Status, as of 20 October 1944," D. G. Christopherson, Ministry of Home Security, REN-461.

93. *Note on Airbursts of 4,000-lb. H.C. Bomb with T-51 Fuze*, F. H. East, Technical Note No. ARM-343, Royal Aircraft Establishment, April 1946.

94. *Interim Report, February 15 to March 7, 1945*, A. V. Astin to Dr. Alexander Ellett.

95. *Inflammability of Mustard Chargings in British Bombs A/C LC 500-lb Mark II Equipped with T-51 Fuzes*, San Jose Project Report 71, June 23, 1945.

96. *Optimum Height of Setting for T-50 Fuze on Blast Bombs, A/C LC 500-lb Mark II Charged Dyed Methyl Scelicyliate and Dropped onto Jungle*, San Jose, Project Report 69, Chemical Warfare Service, June 22, 1945.

97. *Multiple Bomb Assessment of Blast Bomb A/C LC 500-lb Mark II Fitted with T-51 Fuze and Charged HT When Dropped from High Altitudes into Jungle Terrain*, San Jose, Project Report 73, Chemical Warfare Service, July 28, 1945.

98. *Statistical Tables for Biological, Agricultural and Medical Research*, Fisher and Yates.

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Contract Number	*Name and Address of Contractor**	*Subject*
OEMsr-258	Friez Instrument Division, Bendix Aviation Corporation Baltimore, Maryland	Studies and experimental investigations in connection with continuous development work on special radio devices.
OEMsr-343	Westinghouse Electric and Manufacturing Company Baltimore, Maryland	Studies and experimental investigations in connection with the development of special radio devices.
OEMsr-500	Western Electric Company, Inc. New York, New York	Studies and experimental investigations in connection with the development of electronic devices.
OEMsr-528	National Carbon Company, Inc. New York, New York	Production of small batteries suitable for operation at low temperatures.
OEMsr-611	General Electric Company Schenectady, New York	Studies and experimental investigations in connection with the development of miniature vacuum tubes, and report the results thereof.
OEMsr-566	Raytheon Production Corporation Newton, Massachusetts	Studies and experimental investigations in connection with the development of miniature vacuum tubes.
OEMsr-630	Sylvania Electric Products, Inc. Salem, Massachusetts	Studies and experimental investigations in connection with the development of miniature vacuum tubes having a very low microphonic output.
OEMsr-769	University of Iowa Iowa City, Iowa	Studies and experimental investigations in connection with development work on special electronic devices and associated equipment.
OEMsr-866	Philco Corporation Philadelphia, Pennsylvania	Studies and experimental investigations in connection with the development of special radio devices and associated equipment.
OEMsr-885	Emerson Radio and Phonograph Corporation New York, New York	Studies and experimental investigations in connection with and carry on continuous development work on special radio devices and associated equipment.
OEMsr-887	Washington Institute of Technology Washington, D. C.	Development of accessories for special electronic devices and associated equipment.
OEMsr-905	Western Electric Company, Inc. New York, New York	Studies and experimental investigations in connection with the development of special electronic devices.
OEMsr-941	Federal Telephone and Radio Corporation East Newark, New Jersey	Studies and experimental investigations in connection with the development of special selenium rectifiers.

* The National Bureau of Standards, which served as the central laboratories for Division 4, NDRC, did not operate under a contract but as a government agency on a direct transfer of funds from OSRD.

Contract Number	*Name and Address of Contractor**	*Subject*
OEMsr-949	University of Florida Gainesville, Florida	Conduct theoretical studies and experimental investigations in connection with problems peculiar to special electronic devices for ordnance application.
OEMsr-954	The Zell Corporation Baltimore, Maryland	Furnishing machining facilities in connection with development of special electronic devices.
OEMsr-980	Zenith Radio Corporation Chicago, Illinois	Studies and experimental investigations in connection with development of special electronic devices.
OEMsr-981	Knapp-Monarch Company St. Louis, Missouri	Studies and experimental investigations in connection with the development of special power supplies and associated equipment.
OEMsr-1003	Radio Corporation of America Harrison, New Jersey	Studies and experimental investigations in connection with development of special miniature vacuum tubes.
OEMsr-1106	Westinghouse Electric and Manufacturing Company Washington, D. C.	Pilot production of special electronic devices.
OEMsr-1109	General Electric Company Schenectady, New York	Studies and experimental investigations in connection with development work on special electrical and radio devices and associated equipment.
OEMsr-1113	Emerson Radio and Phonograph Corporation New York, New York	Manufacture and delivery of special electronic devices.
OEMsr-1117	Globe-Union, Inc. Milwaukee, Wisconsin	Studies and experimental investigations in connection with development of special electrical and mechanical devices.
OEMsr-1133	Zenith Radio Corporation Chicago, Illinois	Manufacture and delivery of special electronic devices.
OEMsr-1134	Knapp-Monarch Company St. Louis, Missouri	Manufacture and delivery of special power supplies.
OEMsr-1161	The Rudolph Wurlitzer Company North Tonawanda, New York	Studies and experimental investigations in connection with the development of special electronic devices.
OEMsr-1163	The Rudolph Wurlitzer Company North Tonawanda, New York	Manufacture and delivery of special electronic devices.
OEMsr-1196	Philco Corporation Philadelphia, Pennsylvania	Manufacture and delivery of special electronic devices.

Contract Number	*Name and Address of Contractor**	*Subject*
OEMsr-1227	Bowen and Company, Inc. Bethesda, Maryland	Furnish necessary machine shop and assembly facilities for the development of special electronic devices.
OEMsr-1251	General Electric Company Schenectady, New York	Manufacture and delivery of special electronic devices.
OEMsr-1378	Raymond Engineering Laboratory Berlin, Connecticut	Studies and experimental investigations in connection with development of special electronic devices.
OEMsr-1437	The General Instrument Corporation Elizabeth, New Jersey	Studies and experimental investigations in connection with development of electrical and mechanical devices.
OEMsr-1477	Zenith Radio Corporation Chicago, Illinois	Development and production of special electronic devices.
OEMsr-1500	Emerson Radio and Phonograph Corporation New York, New York	
OEMsr-1501	Solar Aircraft Company San Diego, California	Design and produce donut-type setback arming devices for use on British rockets equipped with VT fuzes.

SERVICE PROJECT NUMBERS

The projects listed below were transmitted to the Executive Secretary, NDRC, from the War or Navy Department through either the War Department Liaison Officer for NDRC or the Office of Research and Inventions (formerly the Coordinator of Research and Development), Navy Department.

Service Project Number	*Subject*
	Chemical Warfare Service
CWS-19	Development of an influence fuze for airplane spray apparatus.
	Ordnance Department
OD-27	Development of proximity (influence) fuzes for bombs and projectiles.
OD-191	Development of VT fuze and UHF and VHF circuit techniques.
OD-192	Development of counter-countermeasures for VT fuzes.
	Signal Corps
SC-38	Field testing equipment for proximity fuzes.
SC-40	Substitute for dry battery BA-55.

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The subject indexes of all STR volumes are combined in a master index printed in a separate volume. For access to the index volume consult the Army or Navy Agency listed on the reverse of the half-title page.

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